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ELECTRICAL SECTION.

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Telephone Line Engineering.*

BY C. J. H. WOODBURY, Boston, Mass.,
Assistant Engineer American Telephone and Telegraph Company.

The purpose of all applications of electricity, excepting those of industrial chemistr , is warranted, because it overcomes the impediments of distance.

The amount of capital invested in electric lines, and the rapid depreciation to which they are subjected, renders their construction a matter of importance.

Methods of standard aërial and underground-line construction were shown, and also numerous views showing the methods of overcoming the difficulties through mountains, over rivers, spanning gorges and the savannahs in the southern part of the country.

The growth of the Bell Telephone System has progressed at the annual rate of 29 per cent. compound interest during the past five years, which is over three times the rate of increase during the preceding fifteen years.

The cause of this augmented growth was stated to have been the increased value of the telephone service resulting from the construction of long lines connecting even villages and small towns, as well as cities, in one intercommunicating system, which afforded facilities for that conference which is the fundamental element in commercial transactions.—THE EDITOR.

The wonders of the telephone as the most subtile of physical apparatus, yet so simple as to be the only electric

*Illustrated by lantern slides showing methods of telephone line overhead and underground construction.

device operated without skill, an invention without precedent which has also escaped improvement, has worthily been the theme of frequent portrayal, which has also been devoted to that concentration of applied science upon the switchboard and the transmitter, each of them essential adjuncts in the development of the telephone system.

The salient characteristic which justifies all commercial applications of electricity, except those of industrial chemistry, is that it overcomes the impediment of distance, and it is essential that the conductors spanning these long extents, free from direct supervision, shall be as permanent as possible in order to maintain conditions of constant service.

The amount of capital amassed in the approximately 4,000,000 miles of line construction necessary to connect together in a unity the subscribers of the Bell telephone system is of itself a warranty as to the importance of the subject; while the rapid depreciation to which most of this property is subjected requires both technical skill and business judgment to decide upon the most judicious methods of construction of this vast plant, amid varying circumstances of natural conditions and commercial use, in order to reach the most economical point of investment.

Analyze the general problem as one may, and standardize the general methods to cover a wide range of circumstances, yet there are exigencies and varying conditions which require the exercise of that type of constructive engineering which "does things."

"The picture is first rate, but we built the bridge last night," said the Maine lumberman in the army to his West Point commander.

The application of mathematical principles is essential to any constructive work which is not merely a repetition of precedents, and the ordinary precedents of safe construction have been established upon the wrecks of past failures perhaps for generations agone.

In this paper it is proposed to submit largely by lantern slides some of the engineering difficulties which have been met in line construction and the manner in which these ob-

stacles have been overcome, as well as ordinary methods of standard construction.

The electrical problems form a subject apart from that of this paper.

The increase of every commercial application of electricity to meet the demands to supply service to patrons has been so great that an essential portion of every problem in constructive electricity must take into consideration provisions for future growth as well as the inevitable depreciation.

POLES.

Although 45 per cent. of the wires are on poles, the total extent of the pole lines exceeds the length of the underground conduits, as the latter are used only in cities where the conduits contain a greater number of lines to reach the concentration of patronage.

The extent of the pole lines is shown by the fact that in the Bell telephone system there are approximately 6,300,000 poles, and about 1,000,000 are required annually for replacement and for extension of lines.

A number of years ago a large collection of logs, known as the Joggins raft, was towed from Nova Scotia to New York, and this raft contained many long poles which were not suitable for masts.

Some of these long poles were used for the largest pole line ever built, at the westerly side of New York City, and carrying 250 wires each. At the present time there are single underground cables comprised of $4\frac{8}{10}$ times as many conductors, and under the main streets in the principal cities are conduits of sufficient capacity to carry 400 times as many wires as one of these pole lines.

The typical methods of setting poles will first be shown by some representations from standard drawings.

Where the soil is not firm enough to sustain a pole imbedded in the usual manner, security may be obtained by extending the supporting area by plank at the bottom of the excavation and filling the hole with concrete, or braces may rest upon a platform placed on the surface of the

ground, and in some instances these platforms rest upon piles.

In other instances these braces rest upon plank placed underground, or, in place of a single pole, they are set in pairs, either vertical or joined at the top and connected by strong wire at the ground, making what is known as an A pole.

When the line changes its direction or there are other causes to make a lateral pressure against a pole, it is secured by braces or by guys, either running to an anchorage in the earth or to some other object.

When a telephone line is built in or near cities, the close connection with supplies and labor renders that portion of the work comparatively easy, but in the construction of long distance lines across country, connecting various cities, towns and villages within speaking distance of each other, it is necessary to provide means for the execution of the work on an independent basis.

In a suitable locality a camp consisting of a number of tents is pitched, one of them being a dining tent; another is where the cook holds sway, and the engineers' tent, where such details as must be left until the work is in progress receive attention, while several tents are necessary to provide for the sound sleep which awaits the close of a good day's work.

If the route runs through a wooded country, a wide swath is cut in the forest and the post holes may be made by the diggers, or in other instances a charge of dynamite deposited in an auger hole makes quick work, the greatest relative gain being in compact clayey soil.

Meantime the poles have been brought to their sites by teams, and then moved to the exact place by the help of an axle mounted on a pair of wheels termed a dinkey; gains are cut and the cross-arms attached before they are raised, either by all hands with pikes giving a long push, a strong push and a hard push all-together, to change the old aphorism, or if the country is not too rough to permit, a portable derrick mounted on a wagon is drawn to the site, then the horses are taken from the pole and pulling at the rope quickly raise the pole.

Then the derrick wagon is drawn to the next pole and the work proceeds rapidly.

When the line changes in direction, the pole is rendered more secure by guys and the pole line is ready for the wires which are payed out from a number of reels in a wagon, thence passing through a set of guiding holes, which prevent snarling.

The final attachment of the wires to the insulators on the cross-arms is very carefully done, because it is necessary that the wires should be drawn to an extent that they should not sway against each other, and yet not so tightly that the contraction in cold weather would put a stress on the wire which would produce danger of breakage, for at these small amounts of dip in the wires a slight difference in the length of the line will cause a great variation in the stress.

The stresses to which a telephone pole is subject are the result of many and variable combinations of live and dead loads upon a beam fixed at one end and loaded near the other end.

There is scarcely anything in engineering construction so actively the subject of depreciating conditions.

The top is exposed to the weather, and the important section near the surface of the ground is the portion most energetically attacked by decay. The wood is assailed by animal life, whether it be gnawing by horses in town, or the perforation by woodpeckers in remote districts. Poles in wild countries are bitten by bears in search of bees, whose humming is imitated by the vibration of wires, and it is said that in India the tigers use the poles to sharpen their claws upon after the manner of their second cousin, the domestic cat, but with so much more vigor that the poles become weakened.

Not only are they wrecked by storms, but freight-car roofs frequently fly off and strike the poles edgewise with destructive results.

Iron poles are but rarely used in this country, the principal condition governing their selection being on some lines in prairie countries in the West where campers are so prone

to cut down wood poles for fuel, that tubular iron poles have been substituted. In Europe there are many iron poles, and in tropical countries infested with white ants it is necessary to use iron poles or to attach the wires to living trees.

In the Philippines the United States authorities are planting large straight trees to serve as living attachments for telephone lines, as seasoned wood poles decay quickly under the conditions of tropical moisture.

Antiseptic methods for treating poles as a preventive against decay and the attacks of insects have not been so general in the United States as in Europe, as the relatively sparse settlement and distances between cities having the elaborate plant necessary for treatment would make the transportation of the poles for treatment and back to the sites where they are to be used a prohibitive expense.

However, poles treated by creosoting have been used in this country wherever transportation conditions between the saw mill, the treating plant and the sites where they are to be used will permit.

These conditions apply to certain portions of the South, where Southern pine is sawed to dimensions and then treated.

As the cost of this treatment is based on the volume of the timber, these poles are sawed to such proportions of taper as to give the most economical volume of timber to resist the stresses to which the pole may be subjected. The weakest section of these poles, as computed, is from 8 to 10 feet above the ground.

While gravelly soil will hold a pole to the limit of its strength, it is necessary to build lines in many places where such conditions do not occur. The New Orleans and Mobile line, along the north shore of the Gulf of Mexico, traverses marshes composed of soft mud which extends to a great depth, upon which a rank sedge grass grows 12 to 15 feet in height, whose coarse roots form a compact mass about a foot in thickness.

In order to prevent this line from being injured by the fires which rage among these marshes in the early spring, the grass is kept cut to a width of 100 feet along the route.

It has been possible to sustain poles along this route by bolting heavy cross-pieces across them at the ground level, having cut an opening among the roots through which the butt of the pole can be inserted, and then the pole is braced as occasion may require, sometimes in four directions, each of these braces being supported on a cross-piece at the marsh level. In some instances a pair of, or even three, poles are used, each being attached to the same cross-arm.

Similar methods are used in building the lines across the New Jersey flats, although the conditions are not so severe as at some places farther south.

At the Tybee marshes, near Savannah, Ga., the ground is so soft that it cannot be walked upon, and the men engaged in building the line were obliged to lay a line of boards to proceed along the route. When a pole was to be set, cross-pieces were temporarily attached to it near the lower end, and men standing upon these supports "jounced" in unison while the pole was held vertically by pikes.

Under this human pile-driving the pole sinks rapidly, but the mud is so adhesive that in a short time the pole is securely held.

When ground is too wet and soft to permit digging, poles are frequently set by hewing their butts to wedges, and while the pole is held in a vertical position it is grasped by cant hooks and twisted back and forth, causing it to sink, like the ordinary motion used in boring a hole in wood with a brad awl.

When once set, the pole is either held securely by braces or guys, or it may be made firm by driving a wood curb around it, excavating the mud between the curb and the base of the pole and filling the space with concrete.

In sandy soils, particularly in New Jersey, poles are set on the principle of the jet pile, wherever there is a supply of water.

A half inch pipe about 6 feet in length is temporarily attached to the side of the pole, with its lower end at the butt. The other end of the pipe is attached to a garden hose, and when the pole is up-ended the stream of water makes a quicksand into which the pole sinks until the water is shut

off, and the pole is sustained by pikes until the water settles, leaving the pole securely held by the sand, which becomes water-packed around it.

In mountainous countries the ledges are an impediment to excavations for poles, and although dynamite is frequently used, yet poles are set upon rock without excavation and a large number of stones are piled around them in such quantities as to grip the poles securely, although guys are generally necessary.

A pole line is not designed merely on the basis of the stresses to which the pole is subjected in drawing the wires to the necessary tension, for in most northern climates the sleet will at times form upon the wires until they become icy cylinders perhaps 3 inches in diameter, and the problem is not that of the mere added weight, for the force of the wind blowing against this icy sail applies a greater horizontal load, which combines with gravity and produces a resultant force in a diagonal direction, greater than either of the contributing units.

An ice-laden line swayed by the wind may be successfully resisted by the poles until the oscillations of the pendulum reach a synchronism with that of the vibration of some pole on the line which responds in like manner to the rhythm of the consecutive blows across the direction of the line, until the cumulative impact breaks this individual pole. Then adjacent poles are relieved of the pull on one side, and the excessive unbalanced stress breaks them.

Such is the story of a wrecked aërial line, broken by stresses not included in the ordinary course of events, and which must be provided for by large factors of safety.

It is indeed fortunate that meteorological conditions furnishing in sequence rain at just above a freezing temperature, and meeting a colder stratum, without wind, near to the earth, but followed by a gale, are rare and generally are limited to a small area, for they present conditions which cannot be fully circumvented.

Officers of the Weather Bureau reported in connection with a sleet storm of unusual severity, that there had not been similar conditions in that locality for twenty-three years.

The breakages of lines resulting from a severe storm in Southern New England, a few years ago, revealed the fact that the damage was confined to the valleys of the rivers emptying into Long Island Sound, while the storm did not appear to be of sufficient severity to cause any damage to the lines on higher land.

It is claimed that sleet never forms to a destructive extent on the wires in certain portions of the northerly part of the United States, and this may be one of the instances of the rarity of such occurrences.

A pole is not to be compared to a mast upon a vessel, for these extreme conditions of severe exposure to telephone lines occur in winter, when the ground is frozen, and holds the base of the pole rigidly, while a vessel in a gale heels when struck by puffs and the sails "spill the wind," and in this manner the masts sustain exposure to winds which would break them if held rigidly to long-continued impact.

PREVENTION OF CROSSES.

The most undesirable occurrences in connection with the wreckage of aërial lines are the disturbances resulting from the contacts of different electrical systems with each other, when the various lines are so near as to collide, when one or both break.

While the currents used on the telephone system are so minute as to be without power of damage, yet their wires, in crossing the lines of electric lighting or power systems, may in making short circuits cause serious mishaps to the electric lighting or power plant, and in any event materially interfere with the service.

While the imposition of an electric lighting or power current upon a telephone line would destroy the fine apparatus, and perhaps cause other injuries, were it not for the protectors for the purpose of preventing these foreign currents from reaching the subscribers' installations, or the telephone central stations.

It is far better to prevent the occurrence of harmful conditions than it is to abate their injurious results by a temporary sacrifice of the continuity of the service, for the

operation of a protector serves to open the telephone circuit and to prevent the use of the instruments for the time being, until the lines are cleared and the protectors renewed.

The remedy against the liability of such crosses is the simple one stated by a judge of a United States court, in which the decree was given that the distance between the high and low potential lines should be equal to that of the highest pole, so that in the event of the falling of a pole the wires would come short of reaching the other line. In many instances congestion of electric service and narrow streets prevent any such wide separation, and it becomes necessary to take every precaution for substantial construction.

It is necessary for such different lines to cross the others' routes, and in such instances provision against collision is made by the use of extra heavy construction, thoroughly bracing and guying the poles, and arranging against overhauling of the lines in case of their breakage; also guarding the wires so that those on the upper line could not fall over the ends of the cross-arms in case of their separation from the points of support.

As high-tension wires are of larger diameter and fewer in number, their poles should be higher at the crossover.

The crossover span should be so short and at such height that in case of breaking next to an insulator, the remaining portion of the span wire should not be long enough to reach to the lower line.

The necessary height of poles, or the impracticability of placing them in such positions as to provide for the short crossover spans, may sometimes render it unfeasible to adopt this construction, and a grill of hard-wood slats placed at frequent intervals across a pair of steel wires or cables between the two spans interposes a screen which prevents a broken wire on the upper span from reaching the lower span.

In some instances, where there are but few wires in each line, they are attached to the same pole, and the contact is prevented by a frame-work carrying guard wires below the upper line.

It is not as a general principle advisable to use a single pole crossover.

House tops at the first furnished an attractive route for aërial wires, and some of the fixtures for carrying these wires were of great size, but the framing of most buildings is ill-suited to resist the excessive stresses due to such loads, and the introduction of underground conduits has furnished suitable means for such main conductors, but it is necessary to carry branch wires over the tops of houses in order to reach patrons to whom the wires cannot be led in any other manner.

In place of the old timber constructions, suitable iron pipe frameworks are now generally used.

Other continuous structures are used for conveying large numbers of wires, especially bridges and the elevated railways in cities.

AERIAL WIRES.

The aërial wires are so visibly in evidence, and often to an obstructive extent, that they may be cited as the portion of the system which naturally receives especial attention from the public.

Before presenting instances of construction, it is worth while to submit two matters of principles of aërial lines and materials.

The tension on a line suspended between a pair of horizontal supports varies with the sag and is at a minimum when the sag amounts to $\frac{7}{20}$ of the span, and the tension increases whether the sag is greater or less than this proportion.

For example, with No. 12 hard-drawn copper wire, weighing 173 pounds to the mile, and being ·104 inches diameter, and having a span of 130 feet, the minimum tension of 3 pounds would occur if the sag was 43 feet 6 inches, while it would slowly augment with increase in the sag, and if nature had furnished a chasm deep enough for the experiment, it would be expected to reach its breaking tension of 550 pounds at a depth of 16,470 feet, or 3·17 miles.

On the other hand, the increase in tension proceeds rap-

idly as the wire is drawn to approach a straight line, the breaking tension occurring at a sag of $1\frac{1}{2}$ inches.

As a comparison with this instance of the stresses in a local line, in the case of the No. 8 hard drawn copper wire, ·165 inch in diameter and weighing 435 pounds to the mile, as used on long-distance telephone lines, when the span is 150 feet the minimum tension occurs at a dip of 52 feet 6 inches, when it is only $8\frac{3}{4}$ pounds, and in like manner, as in the foregoing instance, its breaking stress of 1,328 pounds would be reached at the slightly less dip of 16,100 feet, or 3·04 miles, still too great to admit of confirmation by direct experiment; but if the wire was pulled until the sag was $2\frac{2}{10}$ inches, it would require the breaking load of 1,328 pounds.

It is desirable that the wires should be drawn tight enough to prevent them from swaying against each other; but it is important that they should not be drawn so tight that the contraction during extreme cold weather should cause the wire to break.

The temperature is carefully noted when lines are being drawn, and the sag is left in accordance with a table based on a factor of safety of five computed for the usual lengths of span throughout a range of natural temperatures.

Natural Temperature Fahrenheit.	Length of Span of Hard-Drawn Copper Wire in Feet.					
	75	100	115	130	150	200
	Sag in Inches.					
— 30	1	2	2½	3½	4½	8
— 20	1½	2½	3	4	5	9
+ 10	1¼	3	3½	4½	6	10½
+ 30	2	3	4	5½	7	12
+ 60	2½	4½	5½	7	9	15½
+ 80	3	5½	7	8½	11½	19
+ 100	4½	7	9	11	14	22½

When a wire is laden with sleet, the strain lengthens the wire and the increased sag diminishes the tension some-

times to an extent sufficient to save the wires, which would otherwise be broken were it not for this elongation.

HARD-DRAWN COPPER WIRE.

The electrical advantages of copper over iron could not be utilized for aërial wires, because commercial copper has so little resilience that it will continually stretch under its own weight and become attenuated to an extent that it will break, until Thomas B. Doolittle produced the hard-drawn copper wire which is now in universal use on aërial lines. The treatment consists in omitting the annealing processes during the latter portion of drawing the wire, but it deviates from the usual method by attenuating the wire by smaller gradations at the latter die plates. The rate of diminishing the wire is wholly an empirical one, at first determined by long and thorough experimentation, and as the hardening occurs for the most part near to the surface, the tensile strength per square inch of section is greater with smaller than with larger wires.

For example, No. 8 wire is ·165 inch diameter and has a tensile strength of 62,100 pounds to the square inch, while No. 12 wire, ·104 inch diameter, has a tensile strength of 64,600 pounds to the square inch.

In comparison with commercial copper wire, which has a tensile strength of about 32,000 pounds per square inch, the strength is nearly doubled. The modulus of elasticity is increased from 12,000,000 pounds to 19,000,000 pounds, or about 60 per cent., while the elongation before rupture is reduced from 35 per cent. to 1¼ per cent.

It will be noted that this remarkable change in the mechanical properties of copper wire is produced entirely by manipulation and without the admixture of any alloy.

Its electrical conductivity is practically the same as that of commercial wire drawn from the same ingots, the slight increase being due to the change in the molecular condition of hard copper.

Mr. Doolittle did not patent this valuable process of the manufacture of hard copper, which has extended the limit of electrical transmission of speech four times the distance

available with iron wire, and has been of incomparable value in other electrical service, and the award to him of the Edward Longstreth Medal by the Franklin Institute in 1898 was an act of most suitable recognition of an invention which has been usefully applied to the service of mankind throughout the world wherever electric wires are spanned.

The relative cost of iron and copper wire is not a measure of the comparable expense of such lines in actual service, as copper does not have, under these conditions of exposure, an oxide of high resistance, and its life has not yet been determined. The value of copper scrap from wrecked or reconstructed lines is about 2 cents a pound less than that of new wire, while galvanized iron line wire costs about 4 cents a pound, and when taken down is of no value, and is generally thrown upon a dump.

The rusting of iron wire at the joints adds materially to the resistance of the line.

A few years ago an iron telephone line crossing swamps near Norfolk, Va., was reported open after a thunder storm, but an inspection showed that there was no break in the continuity of the wires; however, electrical tests revealed that the joints insulated the various sections of the wires from each other, the strokes of lightning having produced oxides of high resistance.

LONG SPANS.

Where lines traverse mountainous districts or water courses it is frequently necessary to build spans of great length, using either one of the special bronzes or steel wire for the purpose.

The Connecticut River at Middletown is crossed by wires having a span of 1,350 feet, suspended between a steel-trussed tower 185 feet high on the east side, and a similar tower on the bluff on the west bank is 85 feet high.

From Enfield to Windsor locks the Connecticut is spanned by a suspension bridge consisting of two steel cables 1 inch in diameter and 955 feet long, to which are fastened 2-inch by 3-inch joists 4 feet 4 inches long set 12

inches on centers. On this bridge are laid four cables containing 100 pairs of wires. The tower on the west bank shown in the foreground is 45 feet high, and the one on the east bank 33 feet high.

The St. Francis River, near Madison, Ark., is crossed by a span of 1,000 feet, with the wires supported upon steel-trussed towers 100 feet in height, as it was necessary that the wires should be clear of steamers on the river, which has a varying level of 30 feet between flood and drought.

At the Raritan Canal crossing, near New Brunswick, N. J., a 60-foot span is raised 112 feet above the canal to avoid the shipping.

There are numerous long spans crossing ponds and rivers not used for navigation at which it is not necessary to erect such high towers or to draw the wires up to a small dip to avoid masts.

Long spans are frequently strung in cases of emergency, as when the flood of June 2, 1903, carried away the bridge crossing the Kaw River at Kansas City, Mo., and also the wires attached to it, a span of wires 900 feet in length was immediately suspended between high spars erected on either bank.

The Missouri River at this city is crossed by a span of 1,500 feet, consisting of fifty No. 8 bronze wires suspended between steel-trussed windmill towers 80 feet in height.

The Delaware River at Yardley, Pa., is crossed by an aërial span of 1,300 feet in length with a dip of 10 feet. In all instances, it is necessary to use great care in the anchorage of these long spans, for a rigid attachment would cause the wires to become broken when swayed by the wind.

In some instances it has proved sufficient to carry the wires through semicircular grooves cut into a curved wood saddle upon each of the towers at the ends of the span, but the recurrence of breakages has been stopped in other cases only by attaching the saddles to springs which will yield to the impact resulting from swaying wires.

The very long spans constructed across the Mississippi, Hudson and Susquehanna Rivers have been advantageously replaced by submarine cables.

The most spectacular work in line construction has been done among the mountain ranges of the West.

Lines have been built against the face of cliffs bordering deep canyons, where it was necessary to incline the poles so that the tops carrying the wires overhang the deep abyss, in order to avoid icicles and avalanches falling down the precipice.

In building telephone lines through this mountainous country, a couple of poles are slung like panniers on the sides of two or three mules tandem, and these sure-footed animals will carry them along the rough trails.

The wire is wound in great lengths in connecting coils, which are placed on the sides of the saddles of a train of pack mules, which are thus connected on one side by wire from coil to coil, around the front of the foremost mule and thence back along the other side of the train.

By removing the last pair of coils and unreeling, and thence in turn to the next coil, the pair of wires for a metallic circuit can be laid down along a route.

The Mosquito Pass, near Leadville, Colo., was crossed at an elevation of 13,130 feet by a line of poles which were set only 15 feet apart at the more exposed places, but even this construction did not resist the storms of winter.

Telephone lines were afterwards maintained through this Alpine exposure by an expedient as far out of the ordinary as the celebrated venture of Lord Timothy Dexter in sending warming-pans to the West Indies, and that was by replacing the line of poles by submarine cable carried to this elevated site in continuous coils, as in the case of wire transportation over the mountain trails upon a train of mules, and laid in trenches among the rocks to avoid any disturbances from avalanches.

There have been instances when it was necessary to make expeditions to these altitudes in severe weather to made repairs.

The rough valleys through which the routes pass are picturesque in summer, but in winter the snow accumulates to such depths that linemen attend to their duties on snow-shoes, reaching the lines on 25-foot poles as if they were wire fences.

Among these mountains are ravines which can be crossed only by long spans, where the difficulties are increased by the inclination between the opposite ends of the span, which produces severe end thrusts at the points of support, which are built of three poles capped by cross-beams, which must be held by the most secure guying.

A few of these spans will illustrate the conditions necessary to be overcome in order to extend the telephone to these isolated mountain towns, at all times difficult of access, and during the long winter a hermitage were it not for this telephone service.

Imogene Basin, Col., at an elevation of 13,700 feet, is crossed by a span of 950 feet, which inclines at an angle of 27°. Near Telluride and the Tomboy mines, ravines are crossed by similar long spans.

A surveying party, arranging for the extension of some of these lines, found the snow to be 20 feet deep in these basins in the middle of July, while avalanches had rolled down opposite sides of a valley, leaving a narrow pass bordered by snow and ice 100 feet in height.

These lines, running from the valleys up to great elevations on the mountains, are charged with atmospheric electricity, particularly in winter, which is discharged to earth by bridging retardation coils across the lines and grounding the central part of the coils.

The surveying party noted that these disruptive discharges of static electricity occurred about sixteen times a second, producing a continuous sound which could be heard by one near to the wires. The mountain appeared to be enveloped by static electricity, the poles and the engineers' transit glowed with St. Elmo's fire, and an irritation was felt at the head, and the hair would fly up if the hat was removed.

This electric envelope did not appear to extend to the ground, as one was entirely free from any sensations when lying down, but if, while in such a position, a hand was raised to about 3 feet above the ground, a sharp sputtering sound of static electrical discharges would occur.

IMPEDIMENTS TO WIRES.

Trees are a serious impediment to wires, and although it is at times feasible to arrange for a severe trimming, yet for the most part such excisions must be made in moderation and the lines arranged to go over or under, or, like the priest and the Levite, "pass by on the other side."

At one of the electric light conventions, a speaker was asked what method was used by his company for trimming obstructive branches, and he replied: "For the most part the electrical method."

While a high-tension circuit, carrying sufficient current, will burn its way through a branch of a living tree, yet the self-interest of all electrical companies, without regard to other important considerations, impel them to the utmost care in avoiding trees.

Considerable damage is done to electric lines by trees felled during gales, and at St. Louis, May 27, 1896, and also at Minneapolis, August 20, 1904, tin roofs have been bodily stripped from buildings and placed upon the telephone wires, the metal contacts connecting various telephone lines causing confused jabber at any listening telephone unequalled since the days of Babel.

Telephone lines are patrolled by inspectors alert to observe incipient conditions of weakness, threatening decay of poles, trees growing too near approach to the lines, possible hazards to the service from other electrical wires, and especially in cases of severe storms is the utmost vigilance necessary to take prompt measures in case of any occurrence which will prevent the subscriber, perhaps a thousand miles away, from having the conference which he has the right to expect when he takes the telephone from the hook.

Useful as the telephone may be in affording facilities for communicating between different portions of a city, there are other methods of reaching one's townspeople—messenger, mail, or, like the leader in a child's game, "send myself;" but there is no equivalent for the question and the answer which can be exchanged between persons 1,500 miles apart, their voices reaching each other in less time than if they were conversing across a room; or, to give a

concrete example, the time for telephonic transmission over the 1,064 miles between Boston and Chicago is ·006 second, while the distance that the voice is transmitted through the air in that time is 6¼ feet.

There are many thousands of miles of telephone lines without poles, for the business of lumbering and the wood-pulp industry is conducted over telephone lines traversing the forests from tree to tree through the wilds.

By the use of the telephone the methods of log-driving have been changed for the better. The facility of communication between different gangs along a stream enables the logs to be conveyed without the disturbances caused by jams, which can be prevented by prompt action, and also avoids the destruction of timber, which would otherwise result from the use of dynamite to relieve these jams.

Smaller and more rapid streams, hitherto unsuited for lumbering, have been utilized by the construction of dams, which husband and release the water as may be considered necessary by the men perhaps miles below, who speak through the telephone to those operating the gate at the dam.

The first telephone line of anything beyond a local line was in a wild country, for during the winter of 1878 telephones were used on the telegraph line connecting the signal service observers at the station on the summit of Mount Washington, N. H., to the base, while the first telephone central station with subscribers, in the present sense of the term, was opened at New Haven, Conn., January 28, 1878, although switchboards were used by associated groups of a few persons prior to that date.

One of the most useful applications of the telephone is in connection with the life-saving service, whose telephone lines extend along the shore, and the patrolman carries a small portable telephone which he can connect at fixtures upon the side of frequent poles, and in this manner communicate to the life-saving station for routine report and to summon help in case a vessel is in peril off the shore.

A telephone is a portion of the elaborate system of police signal in cities, while in smaller towns the simpler form of a telephone in a box serves the purpose.

For the household it bestows an assurance of safety in the facility which it gives to all, the opportunity to summon the fire department or other help in case of emergency.

UNDERGROUND CONDUITS.

The number of wires necessary to supply the patronage in cities so far exceeded the possible capacity of pole lines along the streets that it became necessary to place them underground, and this required the development of the underground conduit and the telephone cable as new arts.

While 55 per cent. of the telephone exchange wires are underground, yet the great number of wires in these conduits in comparison with those on poles makes the number of miles of pole lines throughout the country seventy times the length of the streets occupied by underground conduits.

While no other ratio may give an adequate impression of the predominant use of the telephone for communication over long distances, yet in comparison with the length of steam railroad rights of way in the United States, the length of Bell telephone pole lines exceeds that of the railway system by over 26 per cent.

The first experimenters upon underground systems attempted to make them water-tight, and also insulators, such as a solid mass of asphalt concrete in which wires, frequently without insulation, were imbedded.

The lack of satisfactory results caused the Bell Telephone Company to begin the development of the work under Mr. Joseph P. Davis, Chief Engineer, on the principle of providing a conduit of substantial construction containing ducts in which the cables could be placed or withdrawn, and relying upon the conduit merely to provide a protection against injury.

A conduit was built in Boston in which the ducts consisted of 3-inch iron casing pipes, treated by the hot coal tar process to defend against rusting, which were imbedded in a concrete of eight parts of fine roofing pebbles to only one of cement, and this has remained in good order for twenty-two years.

The manholes were made of brick, covered on the out-

side with coal tar, and the foundations laid on plank cov ered with coal tar before the bricks were laid.

This construction was afterwards used in New York, but there was not a sufficient supply of iron casing pipe in the market to supply the demand, and as it was necessary that the work should proceed as rapidly as possible, other materials for ducts were also used.

Logs were bored from end to end and then squared parallel to this core, and sockets and plugs to fit cut at alternate ends to bring the cores securely in line. The wood was treated by the creosoting process before the logs were laid.

Cement-lined sheet-iron pipe imbedded in concrete was also used in large quantities.

At a later date vitrified clay conduit was introduced, and has been extensively used.

Other materials and methods have been used, notably wood pulp tubes treated with indurating materials to render them impervious to water and a defence against decay.

Tunnels for underground cables have been dug through the soft limestone underlying the city of St. Paul, and one of the largest engineering works of the day is the extensive system of tunnels under the streets of Chicago, which has provision for cables as well as the transportation of material.

In rare instances short tunnels are built, as under the canal and railroad at Trenton, N. J.

In addition to the usual difficulties which beset all constructions under highways, the size of the manholes or underground chambers which afford places for splicing cables or changing their direction, as well as leading them from the conduits to centers of distribution, where the individual pairs of wires branch to the service of patrons, the size of these manholes render other occupants under the streets serious obstructions.

When underground conduits were first built in an Eastern city, the engineer prepared sets of standard drawings, and so many were the modifications rendered necessary by other underground work that only one manhole was built in conformity to the standard design.

A conduit 260 feet long, containing 13 ducts, at Seventeenth Street and Allegheny Avenue, Philadelphia, was successfully lowered 12 inches at one end and 18 inches at the other, on account of a change in the street grade.

When large underground work, such as subways, are built in cities, the changes in conduits as well as lines of pipes and sewers present difficulties of which it can only be said in the present available limits, that the changes were made.

While a trench was being dug for an underground conduit in Rochester, an unexpected ledge was uncovered, there were no facilities for that work at hand, and a steam roller was hired to supply steam for the drills, and the ledge was soon blasted away.

Underground conduits have wrought a great change in the housing of the telephone central station plant, as the rigidity of an underground system requires that the distributing centers should be of equivalent permanency, and the telephone plant could not in such cases be subject to the mutations of leased property, but must own the buildings.

Therefore fireproof buildings have been constructed by telephone companies all over the country, until the Bell Telephone system owns the greatest number of fireproof buildings of any single interest in the country, and its holdings of buildings and land in cities make it a vast realty enterprise.

If the underground conduits remove conductors from vicissitudes of decay of poles, and exposure to storm and the hazards of foreign currents, yet the underground conduits have their share of mishaps.

Breaks in water pipes or sewers disturb the foundations of these conduits, rain storms flood them, illuminating gas percolates into them, waiting to be ignited by a spark from a horse's shoe at some leak around a manhole cover, or it may be lighted by men going to work in a manhole with a lantern looking for trouble—and finding it.

The superficially attractive proposition of joint conduit systems, particularly in connection with a scheme of muni-

cipal conduits for electric wires, has been attended by serious occurrences.

Crosses among high tension conductors in cables occur from time to time, and if the wires of signalling systems were exposed in the narrow limits of a manhole, they would be disabled.

In one city where an inclusive conduit was laid by the municipality, the work was fortunately in good hands, and the manholes were built very large, with the cables of various classes placed on supports upon opposite sides of the manholes, and the cables containing high tension wires enveloped with split underground tile conduit tied together.

The attempt of a municipality to force a Bell Telephone Company into an inclusive underground conduit system under circumstances which were considered to expose their cables to hazardous conditions, gave rise to litigation in which the contentions of the Telephone Company were fully sustained by the Supreme Court of that State.

CABLES.

The necessity for cables was coincident with the decision that underground conduits must be constructed on the "drawing-in" and not on the "built-in" system, and at about the same time it was foreseen that aërial cables must replace the open wiring in cities wherever there were a great number of local wires, on account of their compactness, and greater resistance to storms. For electrical reasons, it is necessary that open wiring must be used for long telephone lines.

The first telephone cables, both aërial and submarine, are believed to have been those used at Philadelphia in 1881, and at that time experimental constructions were being made at Providence, Brooklyn and Boston.

In the latter city parallel rubber-covered wires, giving conditions of such great electrostatic capacity that a mile was the utmost limit of telephonic transmission, were tried, but when about a third of a mile was inserted in a telephone line, subscribers complained that their instruments were becoming worn out, as they could barely hear; and the in-

duction between the parallel wires was so great as to transmit cross-talk between the various circuits.

The induction was stopped by placing the wires in twisted pairs, but the problem of insulation with a low static capacity required long experimentation by many persons. Mr. W. D. Sargent, of Brooklyn, tried paper insulation and found that the static capacity was reduced and the transmission correspondingly improved, which Mr. T. D. Lockwood found to be due to the occluded air among the loosely twisted fibrous paper, and not to the paper as an insulating material.

Mr. John A. Barrett, of New York, was intimately engaged upon experimentation and manufacture of cables, and to him are due many improvements in cable design.

At this time Mr. W. R. Patterson, now of Chicago, was working along independent lines, and made a form of hydraulic press for drawing on the lead cable sheath, which is still in use as the standard method of manufacture, although many changes of detail in the conductors have been introduced, with the result of improving telephonic transmission to over five times that of the first cables using twisted pairs.

The drawing in of underground cables is like the traction of locomotives, an instance of the occurrence of the unexpected. They can be drawn through devious ducts, around turns and across manholes, to an extent which was not anticipated. The early cables were wound with steel wire twisted on a long pitch to carry the stress of drawing in the cable.

Experiments on one drawn through an irregular conduit showed that the pull was about 20 tons, but such severe treatment is now avoided as unnecessary.

The cables are usually drawn in by man-power, either direct or applied to hand winches, but of late mechanical power has been applied to this work. Automobiles have been used for this work, but a cheaper and more efficient means has been reached by a 7-horse-power gasoline engine on a platform wagon, which also carries a winch.

In advance of a cable, the ducts must be first traversed

by a wire to draw the cable, and the forerunner of this wire is either a number of wood rods hooked together and pushed along as section by section is added, and when the length to the next manhole is completed a strong wire is attached to the last rod, and as the first rod is pushed into the next manhole it is inserted in the corresponding duct on the other side of the manhole and pushed and pulled along, or if it is at the end of the cable run, the rods are pulled along and disjointed section by section.

A fine wire is sometimes drawn through a duct by a conical piece of wood with a thin leather washer filling the duct, and forced ahead by the air pressure at the rear, which is exerted through the application of an air pump at the front end of the duct at the next manhole.

This piece of wood is termed the "mouse," and the name is probably responsible for the persistent story that lines are first drawn through the conduits by a fine string tied to the tail of a tame rat who has been taught to do this work.

Cables are applied for miscellaneous other uses outside of conduits wherever the lines need protection against water, moisture or accidental violence. They are used for submarine lines at bridge draws and river crossings, where they appear to be the especial targets for fouling anchors and snarling propellers. The cables across the Mississippi at New Orleans become overlaid by the soft viscous mud of the river, which is so tenacious that it is impossible to pull them up again.

They are applied in tunnel work and in mining, and have even been led to a stranded steamship.

At Honolulu there are especial facilities for laying temporary cables to vessel anchored in the harbor, furnishing them with telephone service when in port.

In all United States seaports, vessels moored to wharves can promptly obtain temporary telephone service, for which wires already are placed upon the wharves ready to be extended to telephones to be installed in the cabin.

The subscribers are reached from underground cables by leading the cable through a pipe from the manhole, thence

turning upward at the side of a pole, near the top of which the cables terminate in a cable box and the wires are separated into their several pairs, distributing to their respective instruments, generally by twisted pairs hung upon poles in rear alleys or attached close to buildings to avoid articles falling from windows or ice from roof cornices.

An entire underground system by which these laterals enter a basement, and thence by inside conductors extend through a building or perhaps an entire block is rare, except in the congested portion of large cities, where the number of patrons is sufficient to require the wires of a cable, and even then it is not always feasible to obtain permission from the several owners to make holes through division walls or to place in a building other wires than those used for the service of the occupants.

The modern office buildings are provided with channels in the walls for telephone wires, and also parallel grooves under the floors in multiples of 3 feet from the front side of rooms, so that wires can be run from the wire entrance of the building up through the floors to positions convenient to reach desk telephones, for as the telephone connections are made in less time than any other service, such as passenger elevators in buildings, or attention by salespeople in stores, so it takes too much time for the average business man to step to the telephone many times a day, and the electrical mountain must go to the commercial Mahomet, by placing the telephone on his desk.

These laterals and distributing pipes conveying the cables branching from the main system are sources of trouble in cold climates, for water penetrates them, usually by backing up from a flooded manhole, and by freezing in the space between the pipe and the cables, crush them until the insulation becomes impaired.

The former course required the expensive method of using a portable steam boiler, generally a city fire engine, to blow in steam from twelve to thirty-six hours to melt the ice, and then cut out the cable, which must be replaced by another one.

The Chicago Telephone Company equipped a wagon with

step-down transformers and conductors, which could be attached to the electric light wires and furnish a current of 700 amperes at a low voltage.

The secondary wires from this wagon were attached by long clamps to the cable sheath at the distributing pole and at the manhole to furnish a current which warms the cable, and in a few minutes the melted ice runs into the manhole.

In some places, where there are not any electric lighting wires within an available distance, an automobile boiler is used to give a supply of steam, at far less cost than a steam fire engine, for which the hire is $5 an hour.

The cable is not disturbed, as it has been found that, although the ice pressure may have collapsed the cable to an extent sufficient to short circuit the conductors, yet the elasticity of the paper insulation is such that in a short time the insulation will be restored.

The damage by freezing does not take place in the horizontal pottery laterals of 3-inch sewer pipe leading from the manholes, but occurs in the iron pipe which comes down the side of the distributing pole and connects to this pottery pipe by an elbow of 3 feet radius and a straight run of 12 feet to the sewer pipe. It is proposed in the future to use sewer pipe runs and elbows.

Although lead-covered underground cables entering buildings or kept in storage are frequently gnawed by rats, who receive a swift retribution in case of cables containing high-tension circuits, yet aërial cables have of late received the attacks of insects which cut through the lead sheaths with their sharp mandibles for the purpose of laying eggs in the interior.

In China and Japan such perforations occur near the bamboo thickets, where an insect which lays its eggs in the bamboo stalks abounds.

This difficulty is met by wrapping such cables with burlap soaked in linseed oil.

In Australia similar difficulties have occurred over a wide expanse of territory, where it has been found that four species of beetles have in this manner perforated lead cable sheaths.

In Texas perforations are quite frequent, but it has not been found what insect produces these holes.

THE RATE OF TELEPHONE DEVELOPMENT.

It has been the endeavor to submit, as far as facilities for illustration provide, some of the obstacles presented by natural conditions to the construction and maintenance of telephone lines, in order to secure an appreciation of the engineering skill which has overcome these obstacles to the extension of telephone service which now knits together in one system over 26,000 different settlements throughout this country.

The establishment of this vast plant from small beginnings was attended for some years with a rate of increase which may appear slow in the light of later events, until the full development of long line service unified the whole into one connecting system, the value of whose service is far in excess of what could have been derived from isolated plants in separated towns.

These wider facilities endowed the telephone service with a higher value whose worth was appreciated, and the installation of telephones became stimulated to such a degree as to tax the resources of the various departments engaged on the work.

During the last five years the number of telephones in the system has increased at over three times the rate during the fifteen preceding years. This increase has been building upon itself like compound interest at the usurious rate of 29 per cent. a year, and compounding each year at this rate would double the number in $2\frac{3}{4}$ years, or the number of telephones has actually increased over $3\frac{1}{2}$ times during the last five years.

Each of these instruments, as soon as installed, comes into full service for connection with other instruments, and thus reciprocally each new telephone adds to the availability and therefore the value of those with which it may be in communication.

During this last five years these additions of 29 per cent. a year have required corresponding amounts for the enor-

mous increase in construction of new plant, which is entirely separate from the maintenance and repairs of the existing property.

> **Truly the fabric of mental fleece,**
> **Resembles a weaver's masterpiece,**
> **Where a thousand threads one treadle throws,**
> **Where fly the shuttles hither and thither,**
> **Unseen the threads are knit together,**
> **And an infinite combination grows.**
>
> GOETHE—FAUST, Sc. IV.

DISCUSSION.

MR. W. C. L. EGLIN.—The section is to be congratulated in having this subject of "Telephone Line Engineering" so ably and beautifully presented this evening. To-day the telephone is no longer looked upon as a luxury but as an everyday necessity. It fills a most important function in the business and social life of not only the cities, but also the suburban and country sections, and it may be looked upon as a necessity on account of the large percentage of the population of the United States which uses the telephone daily. Mr. Woodbury's very broad field has carried us over a wide and extended range of country, from the extreme south, up the "eastern shore" and across the continent to the Pacific Coast. From the illustrations seen it would appear that the principal difficulties to be overcome in telephone line engineering are more mechanical than electrical. Evidently the early constructors were misled, and had in mind putting the wires as high in the air as possible, with the intention, first, of having them as unsightly as possible, and, second, in getting them above the limbs and branches of the trees; overlooking the fact that the trees continued to grow, and it was only a matter of a few years before some of the branches would come in contact with the wires; and, further, that the higher the pole line the weaker the mechanical construction. For example, the illustration of the pole line in the city of New York, which fortunately has now been removed, carried over 200 wires which towered above the surrounding buildings. The unsightliness and danger of this great mass of wires in the

city thoroughfare is forcibly impressed upon you by the illustration. A single cable, or a pair, supported on short poles would have carried all of the conductors in a much more satisfactory and, certainly, in a more permanent and substantial manner than the method used.

The other illustration of large poles were common a few years ago, viz., the distributing poles to which usually an underground cable was attached and the individual lines were run to the subscribers' premises. These poles were mostly unsightly, and in the case of a number of services, when placed in small streets, the wires would spread out like an umbrella over the entire area. This brings out one of the most important considerations, viz., the objections on the part of the property owner or the subscriber to having attachments made to his premises. The citizen frequently complains of the unsightliness of overhead construction, but offers no assistance in the abatement or lessening of the evil. The civic duty of citizens and property owners should prompt them to co-operate and assist the supply companies in maintaining the necessary service-wires in the least objectionable manner. Fortunately, these objections are being removed on account of the greater number of subscribers and the greater familiarity of the public with this class of construction. It can readily be appreciated that these lines could be carried more safely at the rear of the houses, and this would entirely remove the objection of unsightly appearances of distributing poles and wires.

From the illustrations of underground construction we see again that careful mechanical construction is of the first importance. Cables should not only be installed in proper conduits, but in the manholes they should also be properly arranged and carefully installed.

I am sure we all feel indebted to Mr. Woodbury for this most interesting lecture.

Stated Meeting, held Thursday, December 8, 1904.

An Amperemeter for High Potential Currents.

By H. Clyde Snook.

The instrument described is an ammeter for measuring currents flowing in the secondary circuits of induction coils.

A D'Arsonval system is used, modified by placing a small condenser in parallel with the moving coil and its calibration shunt to compensate for the high rate change of current, and by a ground on one side of the system to prevent sparking between the meter parts.

The instrument is especially adapted for use in X-ray work, because it was found that the quantity of X-rays was directly proportional to the current flowing in the tube.—The Editor.

This instrument has been devised expressly for measuring direct currents of a very high voltage. The immediate cause for its existence is the desire on the part of radiographers and physicians to know the capacity of the output of their induction coils and static machines.

Some work bearing directly on this line of investigation has been done by several workers recently. Gaiffè, a Frenchman, has produced a meter of the hot-wire type for measuring the secondary current of an induction coil, and Professor Sheldon, of the Brooklyn Polytechnic Institute, has conducted a series of investigations upon the static machine.

Fig. 1.

The interest in the matter is not a little, since it concerns the measurement of the dosage in X-ray treatment for therapeutic purposes, and the comparison of currents in Roentgen tubes used for making radiographs.

An induction coil does not deliver a secondary current of steady volume and practically unvarying potential; in fact, quite the contrary. The current and potential vary within wide limits, and the rate change of both is exceedingly high. During one complete cycle of magnetization and demagnetization of the core of an induction coil, we have a current curve in the primary about as shown in *Fig. 2.*

(It is assumed here that the induction coil is being operated by some form of the mechanical make-and-break contact shunted by a condenser.)

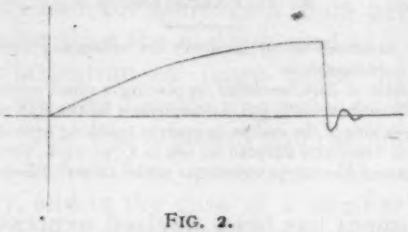


FIG. 2.

It is readily seen that the self-induction in the primary circuit prevents the current from rising suddenly after the contact is made, but that there is a very abrupt fall at break, followed by a slight oscillation due to the condenser. In connection with this curve it is assumed that the self-induction alone is used to limit the maximum current value.

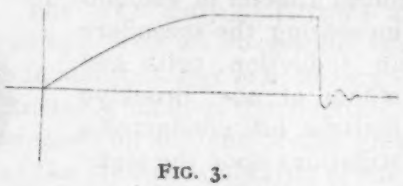


FIG. 3.

Should a higher voltage be used than the self-induction is capable of caring for, and a rheostat be used to control the current, the curve may assume various shapes, depending upon the amount of self-induction and rheostat resistance in the circuit (*Fig. 3*).

FIG. 4.

A curve something like this is obtained when there is a large enough resistance in the circuit that the rise of current is limited by the ohmic resistance, and not by the self-induction of the primary (*Fig. 4*).

This curve indicates too small a value of self-induction to prevent a rapid rise of current during part of the time of "make."

The current curve in the secondary circuit of the induction coil would be as follows if we assume a current curve in the primary, as in *Fig. 5*.

It should be remembered that the frequency of these cycles is usually something over 25 a second. The range of frequency of interruption of mechanical interrupters of different makes is from about 25 a second to about 300 a second.

Referring to curve (*Fig. 5*) of the secondary current, there is noted a long part of the wave induced in the secondary

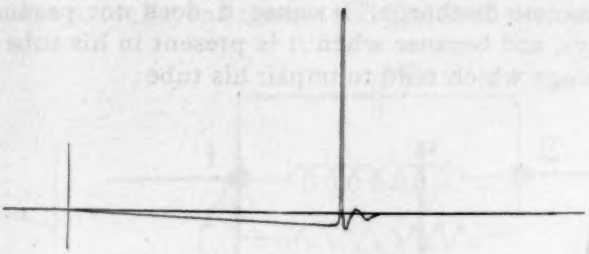


FIG. 5.

during the time of contact, that is, during the time of the rise of the current in the primary.

This part of the curve, together with the other small wave at the end of the curve, has been dubbed the "inverse discharge," as it is of opposite E.M.F. to that of the part of the curve corresponding to the long spark and the "break" of the interrupter.

It is an "inverse discharge" because it is in inverse direction to the direct or long spark of the coil, and is very small in coils which depend upon the self-induction of the primary coil to control the current value in the primary circuit. In coils which are operated upon 100 or 220 volts, primary current rheostatic control is used, and there is apt to occur either a condition found in curve (3), where there is a large loss of energy in the rheostat, or a high rate change of current rise as in curve (4), which is productive of the

"inverse discharge." This need of a means of controlling the primary current by means of the self-induction is very nicely provided for in coils operating upon low voltages, as obtained from batteries, by the use of a value of self-induction high enough that the current can be controlled entirely by altering the length of time during which current is permitted to flow in the primary circuit, that is, the length of "make."

The obvious cure for the rheostatic loss and for the presence of the "inverse discharge" is a means for varying the self-induction of the primary circuit to suit the current used in it.

It is of great concern to the Roentgenologist to dispense with the "inverse discharge," because it does not produce usable X-rays, and because when it is present in his tube it does two things which tend to impair his tube:

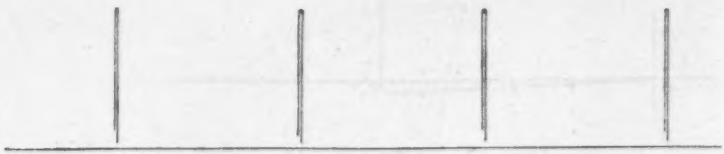


FIG. 6.

(1) When it is passing through the tube the platinum anode temporarily becomes a cathode, platinum is carried off by the cathode streams and plated on the inner walls of the glass tube, rendering them more opaque to the passage of the Roentgen rays and presenting a very large absorption surface whereby the gas of the tube is rapidly occluded and the vacuum raised beyond a point where it is manageable.

(2) When the anode becomes a cathode the occluded gas which it holds is very rapidly given up to the gas of the tube vacuum and a sudden lowering of the vacuum is apt to occur, especially with new tubes. The practical result is that when the inverse discharge is allowed to enter the tube it does not produce usable X-rays, and it causes a temporary lowering but a subsequent permanent raising of the vacuum of the tube.

Though it is a part of the output of the induction coil, the inverse discharge is not usable in a Roentgen tube and is not measured by the instrument we are discussing. The current which the X-ray man uses in his tube is a number of disconnected unidirectional impulses separated by intervals long in time when compared with the length of their own individual duration (*Fig. 6*).

CURVES OF CURRENT IN A ROENTGEN TUBE.

This instrument is a D'Arsonval system adapted to integrate the waves of current above shown and give a continuous reading of the same.

The frequency of the occurrence of the waves is in every instance far beyond the natural period of the moving system

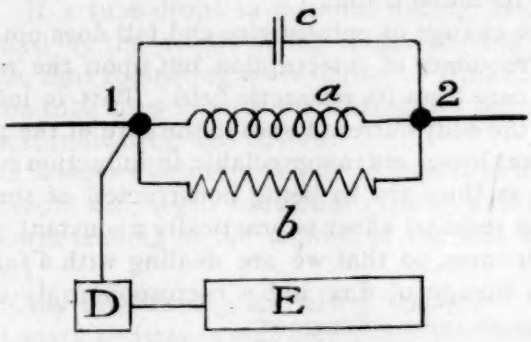


FIG. 7.

which is damped in the usual manner by having the moving coil wound on a conducting frame.

Diagrammatically the instrument (*Fig. 7*) is as follows: *1* and *2* are the binding posts; *a* is the moving coil; *b* is the calibration non-inductive shunt; *D* is the permanent magnet with its core; *E* is the iron case of the instrument and *c* is the small mica condenser.

D is seen to be connected to the post *1*, and *E* is connected to *D*.

The entire instrument is mounted upon an insulating pillar; and the case, magnet and core, with the moving system and shunt coil are all connected together so that they may

rise and fall in potential together, in unison with the varying potential of the secondary circuit.

It is readily seen that the only difference of potential between the meter parts is thus made to be merely the drop through the two coils.

The question of high insulation to withstand high potentials is thus prevented from being raised, and the only insulation employed is that ordinarily used in direct-current measuring instruments.

Due to the very high rate change of current, the self-induction of the moving coil would prevent its taking its full proportion of the current. It was found in practice that the E.M.F. induced between turns was high enough to produce internal sparking in the moving coil and sparking from the coil to its metal frame.

The rate change of current rise and fall does not depend upon the frequency of interruption but upon the rate with which the core loses its magnetic field. This is influenced largely by the eddy current losses in the core of the primary. Eddy current losses are inappreciable in induction coil cores laminated as they are by being constructed of small iron wires. The residual effect is practically a constant quantity in the open cores, so that we are dealing with a fairly constant rate change of flux and a correspondingly constant rate change of induced current.

At *c* we have the condenser, which acts as a hold-over device, as a condenser to take up the surges of current and deliver them more steadily to the moving coil. In this manner the effect of the self-induction of the moving coil is neutralized and the drop in potential between the meter posts more nearly approximates the ohmic fall of potential of the two coils.

As a matter of course, if the "inverse discharge" is permitted to pass through the meter, the meter reading will be the algebraic sum of the integrated values of the direct and inverse currents. This will result in a reading less than the correct value of the direct discharge.

Several methods are used to prevent the passage of the "inverse discharge," and it is usually accomplished by inserting a series spark-gap or a valve tube or both in the

secondary circuit in series with the X-ray tube. As previously mentioned, a preventive measure is the use of a high value of self-induction in the primary circuit.

The currents obtained from static machines are quite steady direct currents when oscillations are not set up in leyden jar or other capacity circuits connected with them, and this instrument is naturally adapted to the measurement of the currents delivered by such machines.

Decidely interesting results are obtained from comparisons of readings of the currents taken by Roentgen tubes on different types of coils.

A soft tube takes much more current than a hard tube even when both are operated on the same coil without having made any change in the coil adjustments. In fact, the same tube when hard takes much less current than when it is soft. If a tube drops in vacuum during use, the fact is announced by the needle of the meter moving upward on the scale, thus indicating more current. And if, on the contrary, the tube rises in vacuum during its use, the needle falls back, indicating less current.

If the inverse discharge begins to pass into the tube, the meter-needle will begin to retreat rapidly, and will give a much lower reading as the volume of the coil discharge is increased.

An X-ray tube having an initial resistance of 3 inches parallel spark resistance will take much less current than a spark gap of 3 inches of air. That is, the change in resistance of the X-ray tube when it takes current is much less than the change in resistance of a spark gap in air, which has the same initial resistance as that of the tube.

For instance, a coil may be adjusted to push 1 milliampere through a tube of 3 inches parallel spark resistance. If the tube be removed and a spark gap of 3 inches in air be made in its stead, 6 or 8 milliamperes will flow across the spark gap without any change in the adjustment of the coil. Ionisation must play a large part in the striking difference found in the degree of the change of resistance.

The current obtainable from an induction coil when sparking in air varies anywhere from zero to 50 milliamperes, depending upon the length of the spark in the air,

the size of the coil, the efficiency of the coil, the resistance of the secondary and the manner in which the coil is operated.

The maximum current which I have been able to obtain from a static machine was $\frac{8}{10}$ of a milliampere. This reading was taken from a large machine having 12 revolving glass plates.

Different induction coils of varying sizes and capacities will deliver to X-ray tubes of varying vacuums currents up to about 14 milliamperes as a maximum.

Standardization of and measurement of X-ray dosage is made possible by the use of this instrument; for the quantity of the X-rays is proportional to the current in the tube.

A comparison of the currents taken by many tubes of different makes and of varying parallel spark resistance has shown that there is scarcely any noticeable difference in the efficiencies of tubes of different makes when they are operated at the same vacuum and with the same number of milliamperes of current.

As a tube grows older and the absorption layer of metallic deposit increases in thickness where deposited on the walls of the tube, its efficiency in radiating X-rays for a given current is somewhat lessened. But any given tube at a stated degree of vacuum gives off X rays in direct proportion to the current which flows through the tube in the proper direction.

We thus have a means of measuring the quantity of X-rays.

It follows that it makes no difference whether the various X-ray workers have static machines or coils, or whether some of them have mercury jet, or electrolytic or other kinds of interrupters, if each worker will record the distance of the anticathode of the tube from the part exposed, the time of exposure, the degree of vacuum of the tube, and the number of milliamperes of current flowing in the tube, his conditions are definitely known and can be duplicated by any other worker.

I wish to state that Messrs. G. Herbert White and Edwin W. Kelly, of the Roentgen Manufacturing Company, have rendered me great assistance in the experiments relating to this instrument.

Determination of Exponents of Adiabatics.

By Thomas M. Gardner,
Member of the Institute.

A paper showing that no simple relationship exists between the values of adiabatic exponents and specific, latent or total heats. Algebraic and graphical methods of determination are used. Tables of average and instantaneous values of n, with their corresponding sheets of curves, are given for steam, carbon disulphide, ether, carbon tetrachloride and acetone. Surfaces having instantaneous exponent, pressure and quality values on coordinate axes are shown.—The Editor.

It was found by Rankine that the law of adiabatic expansion of steam was approximately represented by $pv^n = c$, and gave $10/9$ as the value of n. A series of pressures with their corresponding volumes were chosen, and the final pressures with their volumes obtained. These values were inserted in the formula:

$$p_1 v_1^n = p_2 v_2^n,$$

or $$n = (\log. p_1 - \log. p_2) \div (\log. v_2 - \log. v_1).$$

The several results were averaged, and the number given above for steam was obtained. This value of n is only an average exponent; if from $pv^n = c$ the curve be drawn, it will intersect the ideal expansion line in two points, and will differ at all others.

As the exponent varies for different ranges of expansion on the adiabatic, it is desirable that the instantaneous values of n for a number of equal intervals of pressure be determined. Since

$$pv^n = c$$

$$\log. p = n \log. v$$

$$dp/p = n\, dv/v$$

whence $$dp/dv \div p/v = n.$$

Method of obtaining the slope dp/dv:

p	v	Δv	$\Delta_2 v$	$\Delta_3 v$
p_1	v_1			
		a_1		
p_2	v_2		b_1	
		a_2		c_1
p_3	v_3		b_2	
		a_3		c_2
p_4	v_4		b_3	
		a_4		c_3
p_5	v_5		b_4	
		a_5		c_4
p_6	v_6		b_5	
		a_6		
p_7	v_7			

Suppose it is desired to find dv/dp at p_4. Beginning at v_4, the first, second and third differences are a_3, b_2 and c_1 along the line with an upward trend to the right, and in the downward direction are respectively a_4, b_4 and c_4. Let the differences between p_7 and p_6, p_6 and p_5, etc., be denoted by m, then

$$m\,dv/dp = a_3 + 1/2\,(b_2) + 1/3\,(c_1)$$

and

$$a_4 - 1/2\,(b_4) + 1/3\,(c_4),$$

both series being continued till an order of differences is reached that vanishes. Then

$$2\,m\,dv/dp = (a_3 + a_4) - 1/2\,(b_4 - b_2) - 1/3\,(c_4 + c_1),$$

etc. The first, second and third approximations are the first quantity—the first two and the first three.

The proper second approximation is:

$$2\,m\,dv/dp = (a_3 + a_4) - 1/6\,(b_4 - b_2).$$

This would be exact if v were expressed by equation:

$$v = ap + bp^2 + cp^3 + dp^4.$$

The second equation above is obtained by using Taylor's formula:

$$u_x = u_0 + xa_0 + \frac{x^2}{2}b_0 + \frac{x(x^2-1)}{3}c_0 + \frac{x^2(x^2-1)}{4}d_0,$$

differentiating with regard to x and putting $x = 0$:

$$du/dx_0 = a_0 - 1/6\,c_0 + 1/30\,c_0, \text{ etc.}$$

Since only two differences can be obtained that are sufficiently accurate for use, it is not worth while to consider

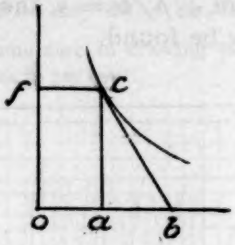


FIG. 1.

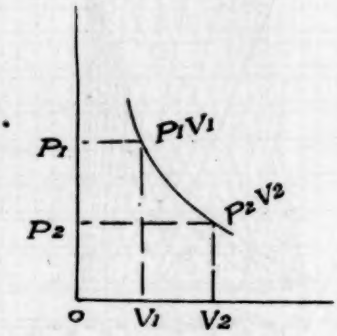


FIG. 2.

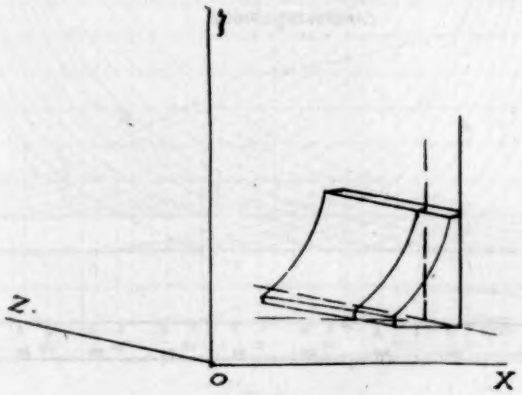


FIG. 3.

the third approximation. So, if from the adiabatics, *Figs. 4, 5, 6* and *7*, a table be constructed of pressures, volumes,

first and second differences, the values of dv/dp may be obtained. Taking the reciprocal of dv/dp and substituting in the formula $dp/dv \div p/v = n$, the instantaneous values of the exponent may be found.

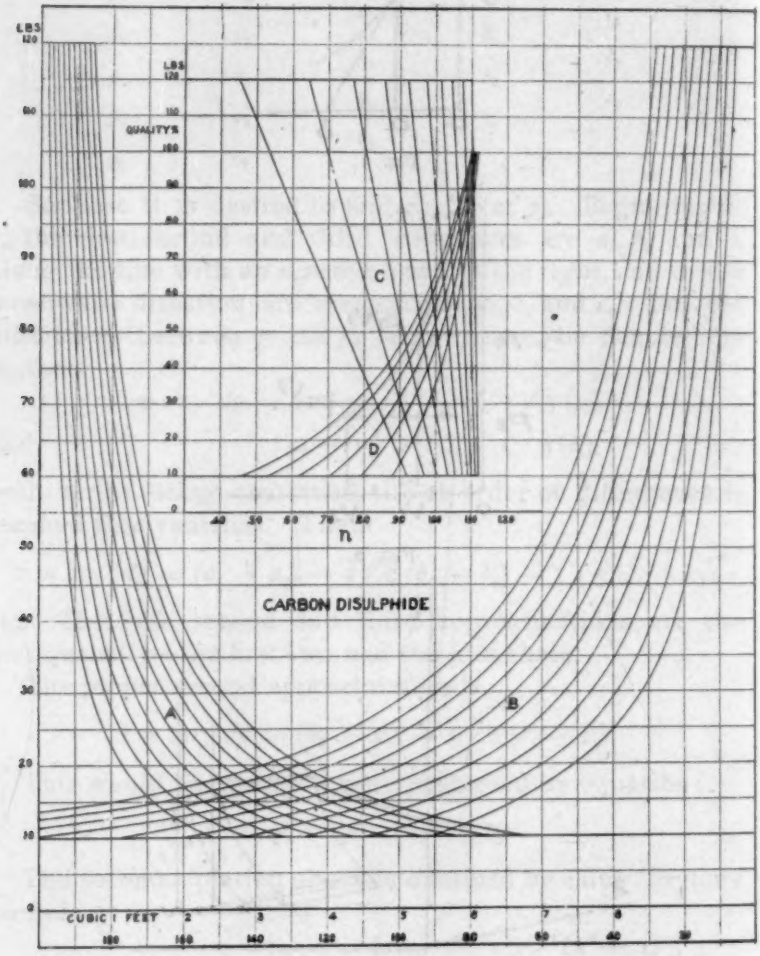


FIG. 4.

Graphical Methods.—In *Fig. 1* let *c* be the point on the adiabatic for which the exponent is desired. Take value

cf ($= oa$). Place a straight edge tangent at c, and read ob, then $oa \div (ob - ab) = n$; for since

$$n = dy/dx \div y/x = ca/ab \div ca/oa = oa/ab = n.$$

NOTE.—Even with extreme care in drawing tangent cb the error in the value of n may be as much as 10 per cent.

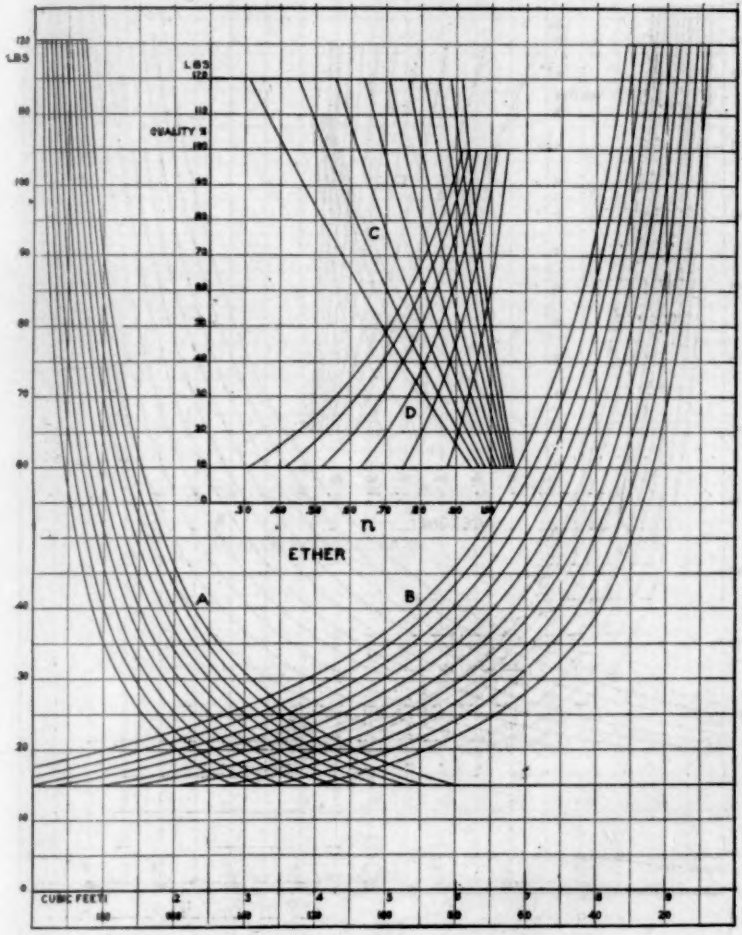


FIG. 5.

To obtain an average value of n.—Fig. 2—On the Y axis of logarithmic cross-section paper lay off of p_1 and p_2 from O. On the X axis do likewise for v_1 and v_2. On either axis lay off $p_1 - p_2$ and and $v_2 - v_1$ from O. Take difference $(p_1 - p_2)$ –

(v_2-v_1) with a pair of compasses and determine the exponent by measuring from *O* and reading the number corresponding.

It has just been stated that Rankine's value of n for adiabatic expansion of steam was 10/9, or 1·11. This was

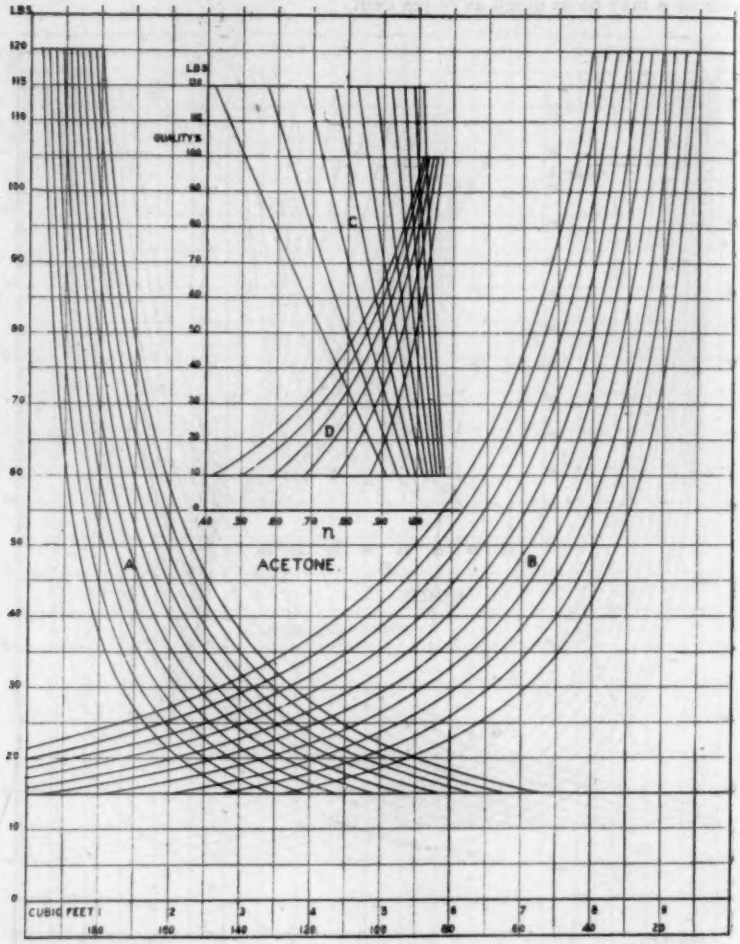


FIG. 6.

later pointed out by Grashof to be too small, but was true for initial dryness fraction of between 75 and 80 per cent. 76 per cent., that is, for a definite mixture of steam and water, and that for expansion from an initial state of perfect dryness, $n = 1.14$.

Zeuner made calculations, using initial pressures of 4, 2 and 1 atmospheres, and final pressures of 2, 1 and 5/10, 1 and 5/10, and 5/10 atmospheres, obtaining the following exponents:

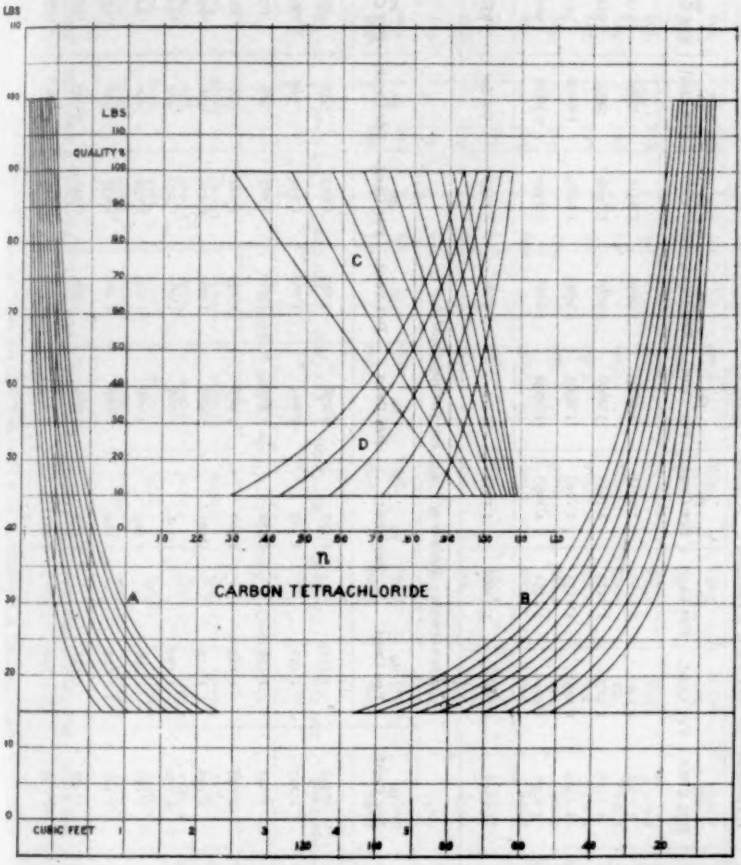


FIG. 7.

$x = 100$ per cent.		$n = 1{\cdot}135$
$x = 90$	"	$n = 1{\cdot}125$
$x = 80$	"	$n = 1{\cdot}115$
$x = 70$	"	$n = 1{\cdot}103$

and finds that for adiabatic expansion of steam whose dryness fraction is between 100 per cent. and 70 per cent., that the value of the exponent is fairly represented by

$$n = 1{\cdot}035 + x/10.$$

STEAM.

Exponents for Adiabatic Expansion. Average Values of "n" for Initial Qualities of

Temperature Range, Deg. F.	Pressure Range, Lbs. Abs.	100 Per Cent.	90 Per Cent.	80 Per Cent.	70 Per Cent.	60 Per Cent.	50 Per Cent.	40 Per Cent.	30 Per Cent.	20 Per Cent.	10 Per Cent.
341 to 228	119·9 to 20·	1·1397	1·1301	1·1185	1·1043	1·0863	1·0630	1·0311	·9854	·91315	·78296
293 " 194	60·45 " 10·2	1·1366	1·1273	1·1175	1·1052	1·0896	1·0691	1·0409	·9995	·93275	·80450
250 " 162	29·86 " 4·96	1·1309	1·1238	1·1151	1·1043	1·0905	1·0723	1·0469	1·0092	·94704	·82378
213 " 135	14·99 " 2·53	1·1291	1·1229	1·1152	1·1057	1·0934	1·0771	1·0542	1·0196	·96170	·84282
Average . .		1·1341	1·126	1·1166	1·1049	1·09	1·0704	1·0433	1·0034	·93866	·81352

Instantaneous Values of "n" for Initial Qualities of

Pressures, Lbs. Abs.	100 Per Cent.	90 Per Cent.	80 Per Cent.	70 Per Cent.	60 Per Cent.	50 Per Cent.	40 Per Cent.	30 Per Cent.	20 Per Cent.	10 Per Cent.
110	1·164	1·151	1·1135	1·117	1·096	1·065	1·019	·958	.854	·657
100	1·159	1·147	1·132	1·113	1·092	1·062	1·019	·960	·864	·680
90	1·153	1·142	1·128	1·110	1·090	1·060	1·019	·965	·874	·703
80	1·149	1·138	1·125	1·107	1·088	1·059	1·021	·970	·884	·728
70	1·145	1·135	1·123	1·105	1·088	1·060	1·025	·976	·897	·754
60	1·141	1·132	1·120	1·1 4	1·086	1·061	1·030	·983	·908	·783
50	1·138	1·130	1·118	1·103	1·086	1·063	1·035	·990	·921	·807
40	1·134	1·126	1·114	1·102	1·086	1 064	1·039	·998	·936	·836
30	1·130	1·122	1·111	1·100	1·085	1·065	1·042	1·009	·952	·867
20	1·125	1·116	1·107	1 097	1·084	1·067	1·045	1·020	·970	·879

The exponent n is practically constant in the 60 per cent. column.

CARBON DISULPHIDE.

				1·097	1·084	1·067	1·045	1·020	·970	·879	F. I.,

The exponent n is practically constant in the 60 per cent. column.

CARBON DISULPHIDE.

Exponents for Adiabatic Expansion. Average Values of "n" for Initial Qualities of

Temperature Range, Deg. F.	Pressure Range, Lbs. Abs.	100 Per Cent.	90 Per Cent.	80 Per Cent.	70 Per Cent.	60 Per Cent.	50 Per Cent.	40 Per Cent.	30 Per Cent.	20 Per Cent.	10 Per Cent.
265 to 135	120·3 to 20·7	1·1127	1·0963	1·0770	1·0542	1·0262	·9922	·9488	·8913	·7338	·6889
205 " 95	58·55 " 10·4	1·1268	1.1131	1·0969	1·0778	1·0554	1·0217	·9916	·9273	·8278	·7166
160 " 60	30·96 " 4·82	1·1294	1·1179	1·1042	1·0912	1·0600	1·0399	1·0042	·9542	·8482	·7476
115 " 32	14·57 " 2·47	1·1344	1·1246	1·1129	1·0984	1·0802	1·0564	1·0242	·9779	·9052	·7727

Instantaneous Values of "n" for Initial Qualities of

Pressures, Lbs. Abs.	100 Per Cent.	90 Per Cent.	80 Per Cent.	70 Per Cent.	60 Per Cent.	50 Per Cent.	40 Per Cent.	30 Per Cent.	20 Per Cent.	10 Per Cent.
120	1·100	1·075	1·044	1·014	·9750	·922	·857	·769	·646	·453
110	1·101	1·078	1·049	1·020	·9815	·933	·870	·789	·670	·494
100	1·102	1·082	1·053	1·024	·9890	·943	·883	·804	·697	·536
90	1·105	1·085	1·060	1·030	·9970	·954	·893	·825	·725	·577
80	1·107	1·089	1·066	1·037	1·007	·966	·913	·845	·753	·620
70	1·109	1·093	1·070	1·043	1·017	·978	·929	·866	·782	·660
60	1·110	1·096	1·077	1·050	1·026	·990	·945	·888	·813	·705
50	1·112	1·098	1·080	1·058	1·034	1·003	·961	·910	·843	·750
45	1·113	1·100	1·082	1·062	1·039	1·009	·970	·921	·859	·770
40	1·114	1·101	1·084	1·065	1·043	1·015	·978	·933	·874	794
35	1·115	1·103	1·087	1·070	1·048	1·021	·988	·945	·890	·815
30	1·116	1·106	1·090	1·073	1·053	1·028	·997	·956	·905	·836
25	1·117	1·107	1·092	1·078	1·059	1·034	1·006	·968	·922	·858
20	1·118	1·110	1·095	1·081	1·063	1·041	1·015	·980	·937	·880

ETHER.

Exponents for Adiabatic Expansion. Average Value for "n" for Initial Qualities of

Temperature Range, Deg. F.	Pressure Range, Lbs. Abs.	100 Per Cent.	90 Per Cent.	80 Per Cent.	70 Per Cent.	60 Per Cent.	50 Per Cent.	40 Per Cent.	30 Per Cent.	20 Per Cent.	10 Per Cent.
230 to 110	120·31 to 19·6	·9911	·9715	·9491	·9236	·8938	·8536	·8163	·7640	·6971	·6048
180 " 80	61·9 " 10·8	1·0170	·9987	·9775	·9528	·9236	·8884	·8448	·7892	·7150	·6069
135 " 55	30·62 " 6·23	1·0359	1·0193	·9997	·9764	·9483	·9137	·8699	·8125	·7329	·6113
95 " 32	14·72 " 3·54	1·0504	1·0352	1·0172	·9957	·9693	·9362	·8940	·8356	·7527	·6202

Instantaneous Values of "n" for Initial Qualities of

Pressures, Lbs. Abs.	100 Per Cent.	90 Per Cent.	80 Per Cent.	70 Per Cent.	60 Per Cent.	50 Per Cent.	40 Per Cent.	30 Per Cent.	20 Per Cent.	10 Per Cent.
120	·917	·885	·852	·812	·764	·710	·640	·557	·450	·312
110	·925	·897	·866	·828	·781	·730	·665	·558	·490	·362
100	·934	·910	·880	·848	·800	·752	·693	·620	·530	·414
90	·945	·923	·896	·862	·820	·775	·721	·653	·592	·465
80	·956	·937	·912	·881	·842	·800	·750	·689	·614	·520
70	·970	·952	·928	·900	·864	·826	·780	·725	·658	·575
60	·984	·968	·946	·920	·887	·853	·813	·763	·704	·631
50	·998	·984	·964	·941	·913	·882	·847	·803	·751	·690
40	1·014	1·000	·984	·964	·939	·920	·882	·845	·801	·750
30	1·031	1·018	1·003	·987	·966	·959	·920	·888	·853	·810
20	1·047	1·037	1·024	1·012	·995	·980	·959	·933	·907	·875
10	1·065	1·047	1·037	1·024	1·010		·980	·957	·935	·941

ACETONE.

Exponents for Adiabatic Expansion. Average Values of "n" for Initial Qualities of

ACKTONE.

Exponents for Adiabatic Expansion. Average Values of "n" for Initial Qualities of

Temperature Range, Deg. F.	Pressure Range, Lbs. Abs.	100 Per Cent.	90 Per Cent.	80 Per Cent.	70 Per Cent.	60 Per Cent.	50 Per Cent.	40 Per Cent.	30 Per Cent.	20 Per Cent.	10 Per Cent.
284 to 158	135·5 to 23·04	1·0413	1·0229	1·0000	·9767	·9473	·9118	·8679	·8120	·7376	·6309
230 " 122	69·5 " 11·77	1·0640	1·0479	1·0292	1·0068	·9797	·9463	·9040	·8482	·7705	·6500
176 " 86	31·2 " 5·42	—	—	—	—	—	—	—	—	—	—
140 " 50	16·6 " 2·69	1·1304	1·1182	1·1036	1·0859	1·0640	1·0640	·9993	·8483	·8723	·7431

Instantaneous Values of "n" for Initial Qualities of

Pressures, Lbs. Abs.	100 Per Cent.	90 Per Cent.	80 Per Cent.	70 Per Cent.	60 Per Cent.	50 Per Cent.	40 Per Cent.	30 Per Cent.	20 Per Cent.	10 Per Cent.
120	1·010	·982	·953	·912	·869	·813	·744	·657	·540	·378
110	1·016	·991	·963	·931	·889	·840	·780	·702	·600	·440
100	1·021	·997	·970	·940	·900	·854	·798	·725	·631	·504
90	1·026	1·002	·978	·950	·912	·870	·819	·750	·663	·547
80	1·030	1·010	·985	·960	·925	·885	·838	·777	·696	·597
70	1·037	1·016	·993	·970	·638	·902	·857	·801	·730	·637
60	1·042	1·023	1·003	·979	·950	·919	·877	·827	·763	·682
50	1·047	1·031	1·012	·990	·964	·937	·900	·856	·799	·727
40	1·053	1·039	1·022	1·002	·980	·954	·921	·884	·834	·772
35	1·058	1·043	1·028	1·009	·687	·963	·933	·900	·853	·796
30	1·061	1·048	1·033	1·016	·996	·973	·945	·915	·870	·818
25	1·064	1·052	1·039	1·022	1·004	·983	·958	·930	·890	·842
20	1·068	1·057	1·044	1·030	1·012	·993	·970	·945	·907	·865
15	1·083	1·062	1·050	1·036	1·020	1·003	·982	·960	·927	·888
10	1·087	1·067	1·056	1·043	1·030	1·013	·996	·975	·945	·912

CARBON TETRACHLORIDE.

Exponents for Adiabatic Expansion. Average Values of "n" for Initial Qualities of

Temperature Range, Deg. F.	Pressure Range, Lbs. Abs.	100 Per Cent.	90 Per Cent.	80 Per Cent.	70 Per Cent.	60 Per Cent.	50 Per Cent.	40 Per Cent.	30 Per Cent.	20 Per Cent.	10 Per Cent.
320 to 176	106·6 to 16·31	·9860	·9664	·9441	·9167	·8947	·8496	·8060	·7524	·6835	·5890
266 " 158	57·95 " 12·01	1·0498	1·0315	1·0100	·9740	·9550	·9183	·8724	·8139	·7320	·6114
176 " 86	16·31 " 2·751	1·0962	1·0822	1·0656	1·0455	1·021	·9898	·9494	·8944	·7977	·6839

Instantaneous Values of "n" for Initial Qualities of

Pressures, Lbs. Abs.	100 Per Cent.	90 Per Cent.	80 Per Cent.	70 Per Cent.	60 Per Cent.	50 Per Cent.	40 Per Cent.	30 Per Cent.	20 Per Cent.	10 Per Cent.
100	·9375	·906	·872	·834	·786	·730	·659	·571	·455	·293
90	·964	·930	·894	·859	·815	·763	·697	·616	·509	·360
80	·973	·946	·916	·883	·843	·795	·735	·660	·563	·428
70	·990	·966	·938	·907	·870	·827	·773	·707	·617	·496
60	1·007	·985	·960	·931	·897	·860	·813	·753	·673	·567
50	1·024	1·006	·981	·957	·926	·893	·852	·800	·729	·639
45	1·033	1.016	·993	·969	·940	·910	·873	·823	·758	·675
40	1·042	1·023	1·004	·982	·954	·923	·888	·846	·787	·711
35	1·050	1·035	1·015	·994	·969	·943	·913	·870	·816	·749
30	1·058	1·044	1·027	1·007	·984	·960	·933	·894	·845	·786
25	1·066	1·054	1·038	1·020	1·000	·979	·953	·920	·876	·825
20	1·074	1·063	1·049	1·033	1·015	·996	·973	·943	·907	·863
15	1·082	1·072	1·060	1·046	1·030	1·013	·995	·970	·938	·901
10	1·090	1·082	1·072	1·060	1·047	1·031	1·016	·994	·969	·940

The tabulated values of n, in the preceding, were computed from a well-known steam table with Vega's logarithms and are essentially the averages from 100 to 70 per cent., inclusive, as found by Zeuner. It is seen that as x decreases, n decreases. For 100, 90, and 80 per cent. qualities at the several pressures n decreases; for 60 per cent. and below it increases. At 70 per cent., n is practically constant. When the curves are plotted, as in *Fig. 9*, a crossing of each other is noticed. This cannot be said of carbon di-sulphide, ace-

FIG. 8.

tone, ether, or carbon tetrachlorides. Ammonia and some of the other vapors have not been considered on account of lack of experimental data for specific heats of the liquids. Alcohol was omitted because of the fact that dissociation takes place during evaporation.

The hyperbola, which is used quite largely as a curve for comparison with the expansion curve on an indicator diagram, would not be traced by the indicator pencil, true

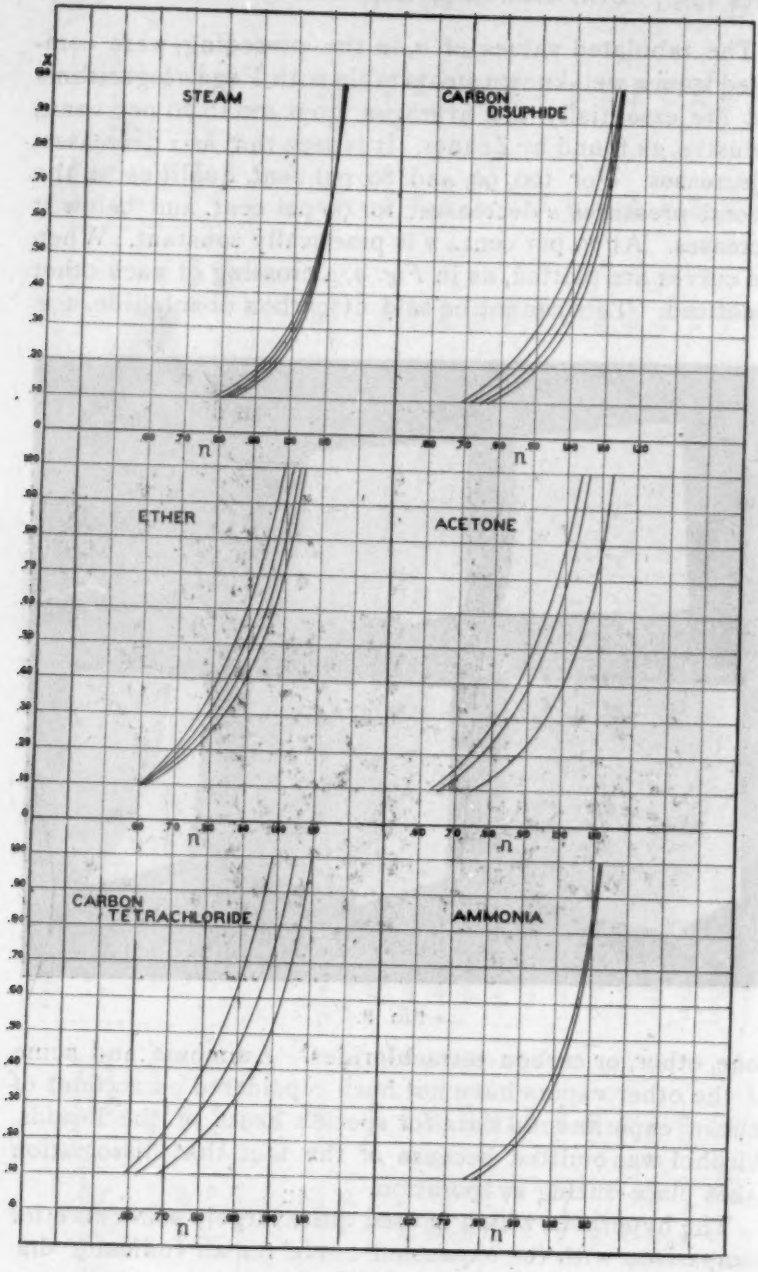

STEAM
CARBON DISULPHIDE
ETHER
ACETONE
CARBON TETRACHLORIDE
AMMONIA
n

FIG. 9.

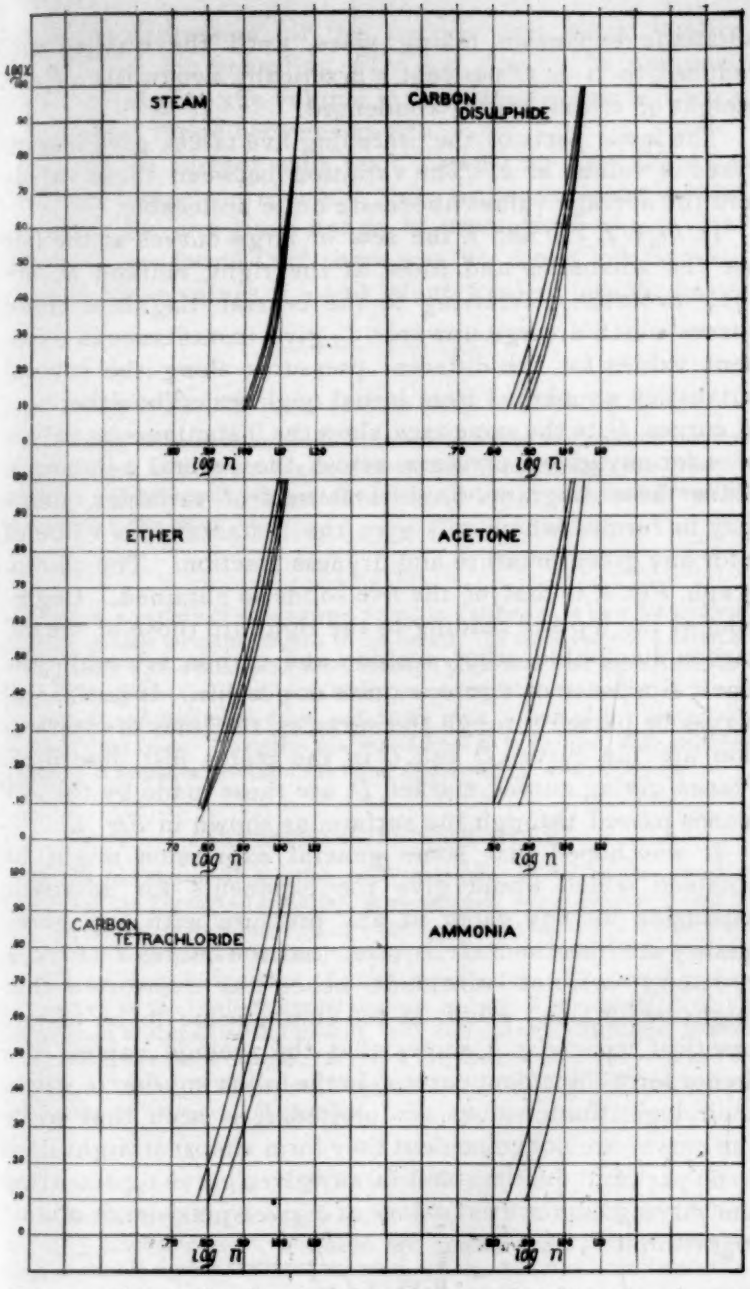


FIG. 10.—NOTE.—The characteristics of log n as plotted have been increased by unity.

adiabatic expansion taking place, until the quality was reduced to 31 or 32 per cent.; practically two-thirds of the weight of steam having condensed.

The lower parts of the preceding five tables give instantaneous values of n. The variation between these values and the average values above are quite noticeable.

In *Figs. 4, 5, 6* and *7*, the sets of large curves at the left are the adiabatics and those at the right, marked *B*, are their evolutes. Referring to the central diagrams, those curves which diverge upwards, *C*, give instantaneous exponent values for the different pressures along the several adiabatics, so marked from initial qualities. The other sets of curves, *D*, to the same axes, show the instantaneous values of n for any given pressure, across the several adiabatics. Since these diagrams have three sets of variables, solids may be formed which will give the instantaneous value of n for any given pressure and dryness fraction. The photograph, *Fig. 8*, is that of the five solids so obtained. Beginning at the top and reading to the right are those of steam, carbon disulphide, ether, acetone and carbon tetrachloride. Their similarity of figure is quite noticeable. If horizontal planes be passed through the surfaces, the lines of intersection are the curves *D* and *C* in the plates just described. Planes giving curves marked *D*, are those made by the *XY* planes passed through the surface, as shown in *Fig. 3*.

It was hoped that some general expression might be obtained which would give the exponents for adiabatic expansion for any vapor at any pressure with any given quality modification. It is seen that the curves *D*, *Figs. 4, 5, 6* and *7*, are not coincident, hence any expression that might be obtained would be too cumbersome to be of any practical use. *Fig. 9* shows that the average values of n do not form coincident curves. In the following *Fig. 10*, where their logarithmic values are plotted, it is seen that while the curves are not coincident they form almost straight lines to 60 per cent. quality; that is, any given curve representing the varying exponential values at a given pressure, is almost logarithmic. That being the case,

$$n = (x / c)^a$$

If now an expression for the 100 per cent. initial quality line of *C*, of the preceding *Figs. 4, 5, 6* and *7*, be obtained, which would give the value *a* at any given pressure, then *n* for a limited range becomes known.

It may be further said, upon comparing exponents for any given temperature, or any given pressure for the several vapors, or for any given range of pressure of the several vapors, it was found that there was no direct relationship between those values of *n* and latent, total, or specific heats.

MAGNESITE AS A LINING FOR FIRE-BRICK.

Magnesite, calcined in an electric furnace, and used as a wash on the fire-bricks lining a melting pot in a calcium-carbide furnace, stood the heat for 200 hours without repair, whereas the bricks that were unprotected required repair after a five hours' heat.

KUNZITE.

Kunzite, a variety of spodumene, found in California, is now cut and sold as a gem in sizes weighing from 1 to 150 carats. In color there is a variation almost white with a faint pink tone, through pink and lilac pink, into dark lilac. The gem is remarkably brilliant, no matter what the color. It is usually perfect and free from flaws, and, when pink, is one of the few natural stones of that color. The price has varied from $6 to $20 per carat, although generally it averages one-third the latter figure.—*Eng. and Min. Jour.*

CARNEGIE INSTITUTION WORK.

At the recent annual meeting in Washington, D. C., of the Board of Trustees of the Carnegie Institution, announcement was made that during the year 114 grants, aggregating $355,070, had been made to further researches in the several branches of science, and $1,000 paid to each of twenty-four research assistants for specified scientific investigation. The larger projects undertaken by the Institute during the year include: The establishment of a Department of Experimental Biology, with Stations at Cold Spring Harbor, L. I., and at the Dry Tortugas, Fla.; of a Department of Economics and Sociology; a Bureau of Historical Research; a Department of International Researches in Terrestrial Magnetism.

SPECIAL STEELS.

L. Guillet reports (*Comptes rendus*, 1904, CXXXIX, 540-542; *Bulletin* Société d'Encouragement, 1904, CVI) that in general the effect of molybdenum in steel is similar to that of tungsten, but the same result is effected with a

smaller quantity of molybdenum, wherefore molybdenum steels may not be more expensive than tungsten steels, and frequently may be substituted for them with advantage. Titanium has practically no influence on the properties of carbon steels. Tin makes steel very hard and brittle. The tin dissolves in the iron and appears to form a compound with it. In tin steels containing not more than 10 per cent. Sn, all the carbon is in the form of pearlite. Tin steels thus resemble titanium steels more closely than they do silicon steels. R. A. Hadfield has patented (British, 25,794, November 26, 1903), an improved method of making manganese steel, which consists in adding an alloy containing 70 to 90 per cent. Mn and less than 3 per cent. C, preferably in a molten condition, to molten decarburized iron, in lieu of the ferro-manganese ordinarily used. In this way it is said to be possible to produce a low-carbon manganese steel which is much less liable to fracture than that heretofore produced.—*Eng. and Min. Jour.*

MAGNETIC STORMS AND SUN SPOTS.

Advices from London state that the data given by E. W. Maunder, superintendent of the solar department of Greenwich Observatory, who recently announced before the Royal Astronomical Society as to the familiar magnetic disturbances which derange the mariner's compass and their relation to sun spots, has created the deepest interest in astronomical circles.

In connection with magnetic storms some kind of solar activity has never been denied. The real point of Mr. Maunder's discovery is the fact that these storms recur at regular fixed intervals. After marking out the times that hundreds of storms were found, some of which corresponded to great sun spots and others which did not, he tried vainly to find a correspondence with the faculæ or flecks of boiling fire on the sun's surface and with the prominences.

At last he noticed that there were frequently a series of magnetic storms at intervals of exactly twenty-seven and one-third days. Sometimes there was no storm at the end of this period, but the storm was repeated after exactly two or three such intervals. Now, twenty-seven and one-third days is the exact time for a point on the sun to go once around and appear opposite the earth again. The storm arrives generally twenty-six hours after the sun spot points directly toward the earth. It is presumed that that time is taken in rushing up particles to reach the earth, though the storm comes again and again after the sun spot has vanished. It is generally just at the time when the place where the sun spot was, in passing; that is, the sun spot has gone, but a stream of magnetic commotion is still proceeding at the same point.

Still more remarkable is the discovery that there are certain favorite points on the sun for sun spots and magnetic streams which continue after the sun spots have vanished. One center of such disturbances is a point on the twenty-second degree of the sun's longitude. It has been pointed out that it is strange that this repetition of storms at intervals of twenty-seven and one-third days has not been noticed before, as Hornstein long ago announced that he detected a minute regular swing of the magnetic needles having the same period.—*Elec. World.*

CHEMICAL SECTION.

Stated Meeting, held Thursday, January 19, 1905.

A Simple Method of Calculating Water Analyses and Amounts of Substances to be Added for Preventing Scale and Corrosion in Boilers.

By Samuel S. Sadtler,
Member of the Institute.

The curves and tables described herewith are intended to fulfil two purposes:

(1) To save the time generally found necessary in calculating water analyses, both in finding the amounts of the bases and acids from the analytical data obtained and in apportioning these to find the probable constituents of the water.

(2) Having analysis of a water, to transpose it into other terms or to find the amount of certain correctives theoretically required.—The Editor.

It has been the experience of the writer that the time necessary to calculate a complete analysis of water for technical purposes (which has to include both sodium and potassium compounds in order to correctly judge the amounts and character of the alkaline earth combinations) is too large a percentage of the time devoted to the whole work. It is not only the time required to convert the quantities found in the analytical determinations into the oxides of the metals, but the still greater amount of time necessary to proportion them with the acid radicles.

In order to make a saving of time possible, I have prepared tables in which corresponding combining weights are referred to the molecular weight of chlorine (Cl_2) and values of from 1 to 9 are given in terms of chlorine, and observing the same ratio, values of chlorine (1 to 9) are then given in terms of all the other substances. The curves are based on the same relations and in addition to the factors represented in the tables, sodium carbonate and soda ash (52 per cent. Na_2O) are plotted, by which in addition to the CaO curve and the Na_2O curve, the calculations for correctives are much simplified. In the case where it is desirable to use lime the impurities must be allowed for, and in the case of sodium hydrate the value found from the curve must be

divided by the percentage of Na_2O in the particular alkali used. The tables and curves are made applicable to several schemes of analysis as follows:

(*a*) That in which the bases are weighed in their usual combinations, with the alkalies as chlorides, and determined in a different sample from the heavy metals and earths.

(*b*) That in which all the determinations, with the exception of chlorine, are made in one sample and the magnesium, sodium and potassium are first weighed up as sulphates, a part of the magnesium afterwards being weighed as oxide and another portion as pyrophosphate. The several weighings containing the same base can be successively transferred into terms of chlorine or into the oxide of the base.

(*c*) A "primary factor" involving the ratio of magnesium chloride to chlorine is given, as the author has been informed that it may be possible to separate magnesium chloride from alkali chlorides by solution in an organic solvent.

Values of those substances never determined as such, are not given in whole numbers or "primary factors."

No relations of calcium sulphate are given in the table, for lack of space, as the values of CaO and So_3 found by the tables may be easily combined. Values for the alkali sulphates and magnesium sulphates are given because of their being sometimes weighed as such.

THE USE OF THE TABLES.

Authorities are somewhat at variance as to the proper way of uniting the basic and acid radicles so as to represent in the report the compounds as they exist in the natural water. This table, however, can be used with any system. The author combines the strongest acids with the strongest bases in turn, and what remains of either base or acid after one proportion is combined with the next strongest base or acid, as may be required. If the acid is in excess the base is converted into terms of chlorine by means of the table, as is also done with the acid. They are then subtracted. The smaller amount is then converted by means of the

table into the compound sought, or in the case of lime and sulphuric anhydride into the oxides and added. The difference is put into the same terms as the next strongest basic radicle, or the opposite is done when the base is in excess. All values are given in terms of milligrams per liter or parts per million. Where more than 1 liter is used, the results are divided by that number, and where the results are to be stated in grains per gallon (U. S. or Imperial) the tables on the right-hand side of each page can be used for the conversion.

Where the amount found in milligrams consists of several figures, they are taken separately and the values found are added, the values corresponding to the second and third decimal places are added after dividing by 10 or 100.

To better exemplify the use of the tables the following analysis is calculated:

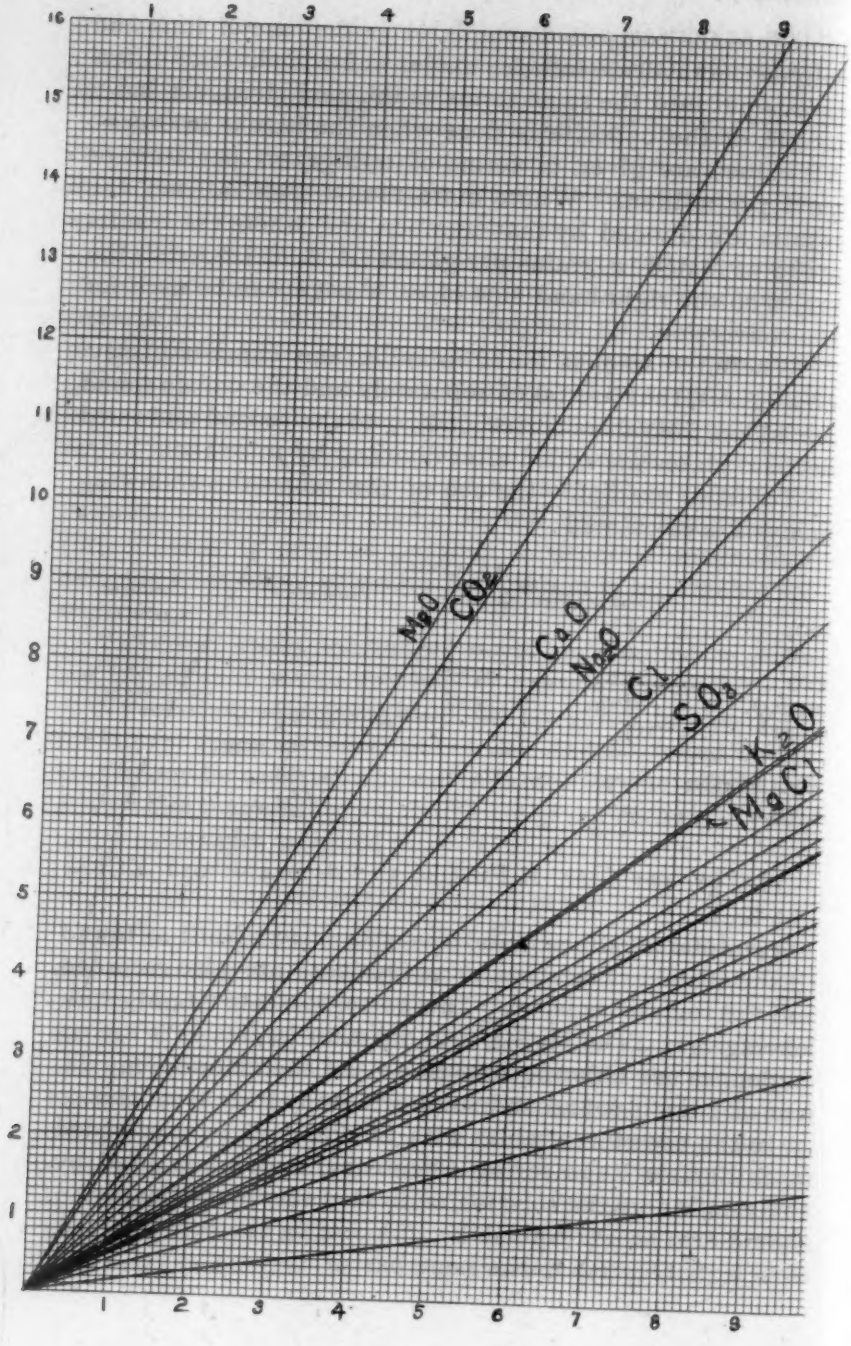
ANALYSIS.

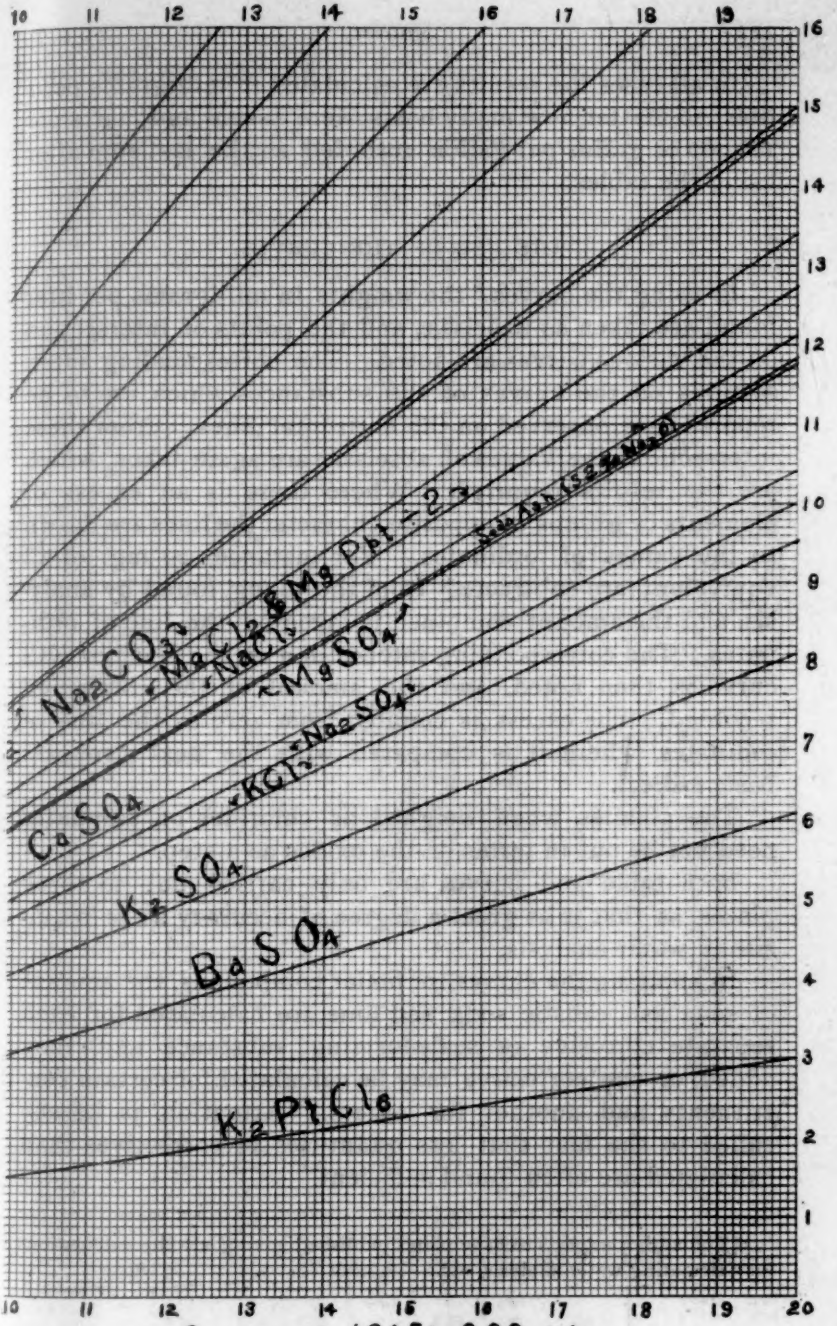
	Grams per liter.	Cl Equiv.	Remainders.	Combined.
SiO_2	2·31			2·31 SiO_2
Fe_2O_3	4·16			4·16 F_2O_3
CaO	26·8	23·87		65·1 $CaSO_4$
$Mg_2P_2O_7$ . . .	24·18	14·18		26.3 $MgSO_4$
$BaSO_4$	159·		Left from Mg 112.	
			" " Ca none.	
Alk. Chlorides	14·0	6·07	·20 .	10·2 NaCl
K_2PtCl_6 . . .	12·1	1·91	6·27	3·82 KCl
Cl	8·18			

12·1 gr. per liter, $K_2PtCl_6 = 3·17 + ·614 + ·032$ KCl = 3·82 KCl.

14·0 total alkaline chlorides — 3·82 = 10·2 NaCl as found by the table. The chlorine equivalents are also recorded and the remainder is ·20. This corresponds to ·314 MgP_2O_7, leaving 23·9. The $MgSO_4$ and chlorine equivalents are recorded, as the chlorine is used up and the chlorine equivalent of lime is found and sulphuric anhydride from this.

In the use of the tables with the method recommended in Stillman's Engineering Chemistry, and much used by analysts, where the solution is divided the quantities found should first be multiplied by 2, 3 or 4, as the case may be, to bring all figures to the same basis.


MgO
CO2
CaO
Na2O
Cl
SO3
K2O
MgCl2



Copyright 1905 by S.S. Sadtler.

In all cases the results are calculated in milligrams per 1 liter, no matter how many liters were taken and parts per 100,000 or grains per gallon recorded as the last step after using the tables.

THE USE OF THE CURVES.

In using the curves * the weights in milligrams per liter found are taken as abscissæ, and the points of intersection on the various curves are noted. The corresponding intersections on the curves of the substances which are to be reported are observed on the horizontal lines. From these intersections the values of abscissæ are again taken, which are the results required. Where there is an excess of elements or groups of opposite character the lines are drawn to the values of ordinates. For instance, 20 mg. of Cl equivalent are subtracted from the 30 mg. found by analysis, and the amount combined is taken on the line of ordinates. The corresponding intersection on the NaCl or KCl curve is then noted, and the amount of the compound recorded. The excess is counted from zero to the line of ordinates, where it is compared with the next strongest basic radical.

The alkalies when weighed as chlorides or sulphates need not be put in terms of the oxides as a step.

Both table and curves are only carried out to three places, as that is as great a degree of accuracy as is requisite in water analysis.

In applying the curves for boiler compounds, the amount of soda ash, caustic soda and lime are calculated for each separate corrosive or scale-forming substance and then added, or one corrective may be calculated for certain constituents and another for others. Attention is hereby called to the fact that less quantities of correctives than calculated are often found sufficient.

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* The author expects to have plates published giving all the calculations for calculating water analysis, etc.

Cl_2.	MgO.	CaO.	Mg ½ Ppt.	$MgSO_4$.	$MgCl_2$.	$BaSO_4$.	$CaCl_2$.	SO_3.	Parts per Mil.	Grains per U.S. Gal.	Grains per Imp. Gal.
1	·569	·790	1·57	1·70	1·34	3·29	1·57	1·13	36	2·0994	2.52
1·76	1	—	2·76	2·99	2·36	—	—	—	37	2·1577	2·59
1·26	—	1	—	—	—	—	1·98	—	38	2·216	2·66
·636	·362	—	1	1·08	·855	—	—	—	39	2·2745	2·73
·587	·335	—	·924	1	7·87	—	—	—	40	2·3327	2·80
·744	·423	—	—	1·27	1	—	—	—	41	2·391	2·87
·304	—	—	—	—	—	1	—	·342	42	2·4493	2·94
2	1·14	1·58	3·14	3·40	2·69	6·58	3·13	2·26	43	2·5076	3·01
3·52	2	—	5·52	5·97	4·72	—	—	—	44	2·5659	3·08
2·53	—	2	—	—	—	—	3·96	—	45	2·6243	4·15
1·27	·724	—	2	2·16	1·71	—	—	—	46	2·6826	3·22
1·17	·670	—	1·85	2	1·57	—	—	—	47	2·7409	3·29
1·49	·846	—	—	2·53	2	—	—	—	48	2·7992	3·36
·608	—	—	—	—	—	2	—	·684	49	2·8575	3·43
3	1·71	2·37	4·71	5·10	4·03	9·88	4·70	3·39	50	2·9159	3·50
5·28	3	—	8·28	8·96	7·08	—	—	—	51	2·9742	3·57
3·79	—	3	—	—	—	—	5·94	—	52	3·0325	3·64
1·91	1·09	—	3	3·25	2·57	—	—	—	53	3·0908	3·71
1·76	1·01	—	2·77	3	2.36	—	—	—	54	3·1491	3·78
2·23	1·27	—	—	3·80	3	—	—	—	55	3·2074	3·85
·912	—	—	—	—	—	3	—	1·03	56	3·2658	3·92
4	2·28	3·16	6·28	6·80	5·36	13·2	6·26	4·52	57	3·3241	3·99
7·04	4	—	11·00	11·9	9 44	—	—	—	58	3·3824	4·06
5·24	—	4	—	—	—	—	7 92	—	59	3·4407	4·13
2·54	1·45	—	4	4·32	3·42	—	—	—	60	3 499	4·20
2·35	1·34	—	3·69	4	3·14	—	—	—	61	3·5573	4·27
2·98	1·29	—	—	5·08	4	—	—	—	62	3·6157	4·34
1·21	—	—	—	—	—	4	—	1·37	63	3 674	4·41
5	2 85	3·95	7·85	8·50	6·70	16·5.	7·85	5·15	64	3·7323	4·48
8·80	—	—	13·8	14·9	11·8	—	—	—	65	3·7906	4·55
6·32	—	5	—	—	—	—	9·90	—	66	3·8489	4·62
3 18	1·81	—	5	5·41	4·28	—	—	—	67	3·9073	4·69
3·94	1·67	—	4·62	5	3 94	—	—	—	68	3·9656	4·76
3·72	2·12	—	—	6·33	5	—	—	—	69	4·0239	4 83
1·82	—	—	—	—	—	5	—	1·71	70	4·0822	4·90

Cl_2.	CO_2.	NaCl.	K_2PtCl_6.	KCl.	Na_2SO_4.	K_2SO_4.	Na_2O.	K_2O.	Parts per Mil.	Grains per U.S. Gal.	Grains per Imp. Gal.
1	·620	1·65	6·86	2·10	2·00	2·46	·876	1·33	1	·0583	·070
1·61	1	—	—	—	—	—	—	—	2	·1166	·140
·606	—	1	—	—	1·22	—	·531	—	3	·1749	·210
·146	—	·241	1	·307	—	·359	—	·192	4	·2332	·280
·475	—	—	3·30	1	—	1·67	—	·632	5	·2915	·350
·500	—	823	—	—	1	—	·438	—	6	·3499	·420
·406	—	—	2·81	·856	—	1	—	·540	7	·4082	·490
2	1·24	3·30	13·7	4.20	4·00	4·92	·175	2·66	8	·4665	·560
3·22	2	—	—	—	—	—	—	—	9	·5248	·630
1·21	—	2	—	3	2·43	—	1·06	—	10	·5831	·700
·292	—	·482	2	·614	—	7·18	—	·384	11	·6414	·770
·950	—	—	6·00	2	—	3·34	—	1·26	12	·6998	·840
1·00	—	1·65	—	—	2	—	8·76	—	13	·7581	·910
·812	—	—	5·61	1·71	—	2	—	1·08	14	·8165	·980
3	1·86	4·95	21·0	6·30	6·00	7·38	2·63	3·99	15	·8747	1·05
4·83	3	—	—	—	—	—	—	—	16	·9330	1·12
1·82	—	3	—	—	3·65	—	1·59	—	17	·9914	1·19
·438	—	·723	3	·921	—	1·07	—	·576	18	1·050	1·26
1·43	—	—	9·90	3	—	5·07	—	1·90	19	1·108	1·33
1·50	—	2·47	—	—	3	—	1 31	—	20	1·1663	1·40
1·22	—	—	8·43	2·57	—	3	—	1 12	21	1·2246	1·47
4	2·48	6·60	27·4	8·40	8·00	9·84	3·50	5·34	22	1·2829	1·54
6·44	4	—	—	—	—	—	—	—	23	1·3413	1·61
2·42	—	4	—	—	4·86	—	2·12	—	24	1·3996	1·68
·584	—	·964	4	1·22	—	1·44	—	·768	25	1·4579	1·75
1·90	—	—	13·1	4	—	6·68	—	2·52	26	1·5162	1·82
2·00	—	3·29	—	—	4	—	1·73	—	27	1·5745	1·89
1·62	—	—	11·2	3·42	—	4	—	2.16	28	1·6329	1·96
5	3·10	8·25	3·43	10·5	10·0	12·3	4 38	6·65	29	1·6912	2 03
8·05	5	—	—	—	—	—	—	—	30	1·7495	2·10
3·03	—	5	—	—	6·07	—	2·66	—	31	1·8078	2·17
·730	—	1·21	5	1·53	—	1·80	—	·960	32	1·8661	2·24
2·38	—	—	16.5	5	—	8·35	—	3·16	33	1·9244	2·31
2·50	—	4·12	—	—	5	—	2·19	—	34	1·9828	2·38
2·03	—	—	14·1	4.28	—	5	—	2 70	35	2·0411	2 45

Cl_2.	MgO.	CaO.	Mg ½ Ppt.	$MgSO_4$.	$MgCl_2$.	$BaSO_4$.	$CaCl_2$.	SO_3.	Parts per Mil.	Grains per U. S. Gal.	Grains per Imp. Gal.
6	3·41	4·74	9·42	10·2	8·04	19·7	9·42	6·78	99	5·7734	6·93
10·6	6	—	16·6	17·9	14·2	—	—	—	100	5·8318	7·00
7·56	—	6	—	—	—	—	11·9	—			
38·2	2·17	—	6	6·48	5·13	—	—	—			
3·52	2·01	—	5·54	6	4·72	—	—	—			
4·46	2·54	—	—	7·62	6·	—	—	—			
8·24	—	—	—	—	—	6·	—	2·05			
7	3·98	5·53	10·99	11·90	9·38	23·0	11·0	7·91			
12·3	7	—	19·3	20·9	16·5	—	2	—			
8·82	—	7	—	—	—	—	13·9	—			
4·45	2·53	—	7	7·56	5·99	—	—	—			
4·11	2·35	—	6·47	7	5·51	—	—	—			
5·21	2·96	—	—	8·89	7	—	—	—			
2·13	—	—	—	—	—	7	—	2·39			
8	4·55	6·32	12·6	13·6	10·7	26·3	12·6	9·04			
14·1	8	—	22·1	23·9	18·9	—	—	—			
10·1	—	8	—	—	—	—	15·8	—			
5·09	2·90	—	8	8·04	6·84	—	—	—			
4·70	2·68	—	7·39	8	6·30	—	—	—			
5·95	3·38	—	—	10·2	8	—	—	—			
2·43	—	—	—	—	—	8	—	2·74			
9	5·12	7·11	14·1	15·3	12·1	29·6	14·1	10·2			
15·8	9	—	24·8	26·9	21·2	—	—	—			
11·3	—	9	—	—	—	—	17·8	—			
5·72	3·26	—	9	9·72	7·70	—	—	—			
5·28	3·02	—	8·32	9	7·08	—	—	—			
6·70	3·81	—	—	11·4	9	—	—	—			
2·74	—	—	—	—	—	9	—	3·08			

Cl_2.	CO_2.	NaCl.	K_2PtCl_6	KCl.	Na_2SO_4.	K_2SO_4.	Na_2O.	K_2O.	Parts per Mil.	Grains per U. S. Gal.	Grains per Imp. Gal.
6	3·72	9·90	41·2	12·6	12·0	14·8	5·28	7·98	71	4·1405	4·97
9·66	6	—	—	—	—	—	—	—	72	4·1988	5·04
3·64	—	6	—	—	7·32	—	3·18	—	73	4·2572	5·11
·876	—	1·45	6	1·84	—	2·15	—	1·15	74	4·3155	5·18
2·86	—	—	19·8	6	—	10·02	—	3·79	75	4·3738	5·25
3·00	—	4·94	—	—	6	—	2·63	—	76	4·4321	5·32
2·44	—	—	16·9	5·14	—	6	—	3·24	77	4·4904	5·39
7	4·34	11·6	48·0	14·7	14·0	17·2	6·13	9·31	78	4·5488	5·46
11·3	7	—	—	—	—	—	—	—	79	4·6071	5·53
4·24	—	7	—	—	8·54	—	3·72	—	80	4·6654	5·60
10·22	—	1·69	7	2·15	—	2·51	—	1·34	81	4·7237	5·67
3·28	—	—	2·31	7	—	11·7	—	4·42	82	4·782	5·74
3·50	—	5·76	—	—	7	—	3·07	—	83	4·8403	5·81
2·84	—	—	19·7	5·99	—	7	—	3·78	84	4·8987	5·88
8	4·96	13·2	54·8	16·8	10·0	19·7	7·0	10·6	85	4·957	5·95
1·29	—	—	—	—	—	—	—	—	86	5·0153	6·02
4·84	—	8	—	—	9·92	—	4·24	—	87	5·0736	6·09
1·07	—	1·93	8	2·44	—	2·88	—	1·44	88	5·1319	6·16
3·80	—	—	26·2	8	—	13·4	—	5·04	86	5·1903	6·23
4·00	—	6·58	—	—	8	—	3·46	—	90	5·2486	6·30
3·24	—	—	22·4	6·84	—	8	—	4·32	91	5·3069	6·37
9	5·58	14·9	63·0	18·9	18·0	22·1	7·89	12·0	92	5·3652	6·44
14·5	9	—	—	—	—	—	—	—	93	5·4235	6·51
5·46	—	9	—	—	11·0	—	4·77	—	94	5·4818	6·58
1·31	—	2·17	9	3·66	—	3·21	—	1·73	95	5·5402	6·65
4·29	—	—	29·7	9	—	15·2	—	5·70	96	5·5985	6·72
4·50	—	7·41	—	—	9	—	3·93	—	97	5·6568	6·70
3·66	—	—	25·3	7·71	—	9	—	4·86	98	5·7151	6·86

THE FRANKLIN INSTITUTE.

Radium and Radio-Activity in General.*

By Robert H. Bradbury.

The atomic theory. The atom an unalterable existence. The radium rays. Corpuscles α-, β- and γ-rays and their effects. The radium emanation. Excited or secondary radio-activity. The radio-active process in comparison to ordinary chemical changes. Its uncontrollable character. Enormous amount of energy evolved. Radio-activity in general. Thorium. Radio-activity of ordinary substances. The evolution of matter.—The Editor.

I. THE ATOMIC THEORY.

The idea that matter is composed of particles with vacant spaces between them is very ancient. It was clearly stated by Democritus, Lucretius and others. But it is only since its restatement by John Dalton, just a century ago, that it has become a scientific doctrine.

The number of different substances known is enormous. Over 100,000 compounds of carbon alone have been prepared; yet when these materials are decomposed or separated into their constituents, we discover that the chemistry of the universe is not so inextricably complex as might be supposed, for as a final result of this decomposing or analyzing process, only about ninety *elements* have been obtained. These are the ultimate constituents of the material world. It is impossible to decompose them into simpler bodies, and it is equally impossible to transform one element into another.

According to the atomic theory, this means that there are only about ninety kinds of atoms. These atoms can combine with one another in an infinite variety of ways,—hence the multitudinous compounds which exist in nature, or have been prepared artificially. Thus, hydrogen (an invisible gas) burns in oxygen (another invisible gas) and water is produced. In this process two atoms of hydrogen unite with one atom of oxygen and produce a compound particle of water which is a group composed of the three. The water can easily be separated into the two gases again,

*A popular lecture delivered before the Franklin Institute, in Association Hall, Philadelphia, Friday November 18, 1904.

and when this is done the group of three atoms is broken up and the hydrogen and oxygen atoms are again separated.

Now, in this union and subsequent separation the atoms of hydrogen and of oxygen are not altered, broken up or destroyed. They are differently grouped, that is all. When an element—as in this case—disappears to form a compound it can always be recovered unchanged in quantity when the compound is decomposed. Accordingly, its atoms have not been modified in any way, but have simply entered into a union with those of the other elements. And from this union they secede—absolutely unchanged—when the compound is split up. It is clear, also, that the fact that one element cannot be converted into another indicates that the atoms are incapable of mutual transformation; that an oxygen atom, for example, cannot be separated into hydrogen atoms.

Thus there grew up, upon a most extensive and solid basis of fact, the conception of the atom as an unchanging existence. Its relations to the other atoms could be changed, but no alteration of any sort could be brought about in the atom itself. Not only the total quantity of matter in the universe, but also the quantity of each chemical element was regarded as constant. Physics takes us to the molecule and leaves us there. Chemistry takes us inside the molecule and informs us about the number and grouping of the atoms. Into the *atom* it was impossible for science to penetrate.

II. THE RADIUM RAYS.

Now, within the last decade we *have* penetrated into the atom and learned something about its structure. Still more surprising, we have observed and studied the transformation of one element into another. Substances like radium have been discovered which are continually emitting in straight lines something which, for want of a better name, we may call *rays*. These rays affect the photographic plate, and this property led to their detection. Afterward it was found that they have many other remarkable properties, which will be briefly discussed almost immediately. Just

now we are specially concerned with the fact that it has been shown beyond doubt that the rays are *material.* Radium continually emits a bombardment or continuous rain of particles with prodigious speed—a speed approaching that of light. By various methods the particles which are continually shot off have been weighed, and they are found to be very much lighter than any atom. The smallest are only about $\frac{1}{1,000}$ as heavy as the hydrogen atom, which is the lightest atom known. The radium atom, then, is continually going to pieces, constantly shooting off minute corpuscles with a speed which would take them around the world in about one-fifth of a second. It is inconceivable that such a speed should be given suddenly to the corpuscle. *It must already possess it inside the atom.*

Thus we are led to think of the atom of radium, and probably of other elements, as a system of small particles, all in very rapid motion. Now and then it happens that a particle acquires such a velocity that the forces—probably electrical in nature—which hold it in the atom are no longer sufficient, and it flies off into space with the speed which it possessed at the moment the atom was forsaken.

This opens up two questions: (1) What are the nature and effects of the particles shot off? (2) What becomes of the portion of the radium atom which remains behind? These questions we shall endeavor to answer in turn.

III. THE RAYS IN DETAIL.

(*a*) *The α-rays.*—Investigation has shown that there are at least two kinds of corpuscles projected from a sample of radium. There is, in the first place, a comparatively large particle, which is thrown of with a speed only $\frac{1}{10}$ that of light, say, 20,000 miles a second. This particle is about four times as heavy as the hydrogen atom and we have every reason to believe that it is an atom of *helium.* These streams of relatively large and slow-moving particles are called the *α*-rays. I have here an instrument devised by Sir Wm. Crookes, by which the blow which the *α*-particle delivers as it strikes an object is actually rendered visible. It is called the *spinthariscope.* It consists of a brass

tube about 2 inches long. In one end is a screen coated with a compound of sulphur and zinc. Close to this is fixed a little copper arrow carrying a trace of radium. In the other end of the brass tube is a lens for better observation. If, after resting the eyes in perfect darkness, you look into the lens, what you see resembles a starry sky, but with the difference that the stars are constantly in motion. Each α-particle, as it strikes the screen, produces a flash which asts only for an instant, then the eye is attracted to some, new place, and so on. The sight is an impressive one, and rightly so, for each flash registers the death of an atom and this is as sublime a spectacle in its way as the death of a universe, though at the other end of the scale of magnitudes.

Since the α-particle is large and not very speedy it is easily arrested. If a radium preparation is wrapped in a sheet of writing paper or a thin layer of aluminium foil, the α-rays are stopped completely, and the β- and γ-rays alone pass through and can be studied separately. Even a few centimeters of air have the same effect. It must be remembered, however, that the term "slow" is only applied to the α-particles by comparison with the more swiftly-moving β-particles. Compared with that of any projectile, the speed of the α-particle is enormous. Weight for weight, for instance, it has 600,000,000 times the energy of motion of a rifle bullet.

(*b*) *β-rays.*—The β-rays have been shown to consist of material particles of about $\frac{1}{1000}$ the mass of the hydrogen atom. Their speed approaches but does not quite equal that of light. On account of their small size and great speed they penetrate matter about 100 times as readily as the α-rays. We may consider that ordinary matter bears much the same relation to them as a very coarse net to an extremely small and agile fish. The β-rays are identical with the *cathode* rays, which are formed at the negative pole when electric discharges pass through a vacuum tube. They are chiefly responsible for the effect of radium preparations upon the photographic plate.

Both the α- and β-rays are turned out of their course

by an electric or magnetic field. This is a proof that they are composed of material particles. In the case of the α-rays the deflection is slight, and its direction shows that each particle carries a *positive charge*. The β-particles are deflected to a much greater extent and in the opposite direction, showing that each particle is charged *negatively*. Calculation shows that, taking the α- and β-rays together, three trillions of particles escape from an ounce of radium per second.

(*c*) *The γ-rays.*—The γ-rays are the most penetrating. They can readily be detected after passing through the human body or a foot of solid iron. A plate of aluminium, $3\frac{1}{4}$ inches thick, cuts them down to one-half their value. There is still some question as to the nature of the γ-rays. They are not at all deflected by an electric or magnetic field, so there is no proof that they are material. They may consist of streams of uncharged particles shot off with immense speed. Uncharged particles would not be deflected, but it is more likely that they consist of an ethereal vibration identical with the Röntgen rays. It seems reasonable to suppose that when a particle is pitched off, the atomic convulsion would set up a shiver in the contiguous ether.

(*d*) *Effects of the Rays.*—Under this head we shall discuss the effects of the three kinds of rays together, just as they escape from the preparation of radium. It must be remembered, however, that if the radium is sealed up in a glass tube, which is commonly the case, the α-rays produce very little result, since they are almost entirely stopped by the glass.

Many substances exposed to the rays become luminous. Zinc sulphide and the diamond are examples. The latter lights up brilliantly, and this has been proposed as a method of distinguishing the gem from its imitations, which remain unaffected. Strong radium preparations are themselves luminous, and may give a light strong enough to read by. But, aside from the rarity of the substance, the presence of large quantities of high-grade radium preparations in the household would be attended with such serious danger that it will never be used as a source of light.

Radium compounds also continuously give off heat. A piece of pure radium would in an hour produce enough heat to raise its own weight of water from the freezing to the boiling point. This means that it would boil 8,760 times its weight of freezing water per year.

The glass in which a radium preparation is kept becomes light violet and finally black. Salt and similar substances are colored blue or green. Dry air, which is ordinarily an insulator, acquires the ability to conduct the electric current under the influence of radium rays, and other gases behave similarly. This effect has been used extensively in measuring the strength of radium preparations, and in investigating the nature of the rays, since it is much more convenient and exact than the photographic action.

The property of the rays of causing the air to conduct the current is so important in the study of the subject that we will endeavor to show it to you on the screen. The *lantern electroscope* which we shall use for that purpose is the property of Dr. John H. Shober, and I am indebted to his kindness for the use of it to-night. It consists essentially of a metal rod, at the upper part of which is attached a strip of aluminium foil. The whole is insulated and supported in a glass box in such a way that the image can be thrown upon the screen by the lantern. You notice that the strip of foil hangs down in contact with the rod, but when the apparatus is charged you observe that the foil stands out at right angles to the rod, because similar electric charges repel each other. This position it will retain for a long time, for since the air is practically an insulator, the charge is lost very slowly. Now a sealed tube containing some radium of 7,000 strength (rather a weak preparation) is introduced.* Immediately the air in the apparatus becomes a conductor and the charge leaks away. You observe that the aluminium leaf gradually falls till it is in contact with the rod. A repetition of the experiment yields the same result. Other things being equal, of course a stronger radium

*It is customary to state the strength of radium preparations in terms of the radio-activity of uranium taken as a unity.

preparation would make the aluminium leaf fall more quickly. With a preparation of 300,000 strength* the fall of the aluminium leaf is instantaneous. It is clear that the method can be used quantitatively. Radium can be identified and determined by it in substances in which the quantity is so small that it would be entirely hopeless to search for it, even by spectroscopic methods. It has been calculated to be about 1,000,000 times as delicate as the spectroscope, and, as you see, it is very rapid and does not entail the loss or destruction of any of the sample tested. Of course, to attain such accuracy requires special elaborate apparatus.

Paper turns brown and falls to pieces under the influence of radium rays. The action on living things is mainly destructive. Seeds lose the power of germination. Some investigators report that bacteria are destroyed, but there is some doubt about this, and it is probable that different organisms differ in their susceptibility. Leavened dough fails to rise if a strong radium tube is buried in it, but when the tube is removed fermentation goes on, so that the yeast is temporarity paralyzed, not killed. *Enzymes* are destroyed. Perhaps the most remarkable of all the effects of the radium rays is their power to prolong indefinitely the larval stage of certain insects. The strength and distance of the radium tube must be carefully chosen; otherwise the worms are killed. When these conditions are right the worms remain in the larval state, while others in a bottle not containing a radium tube have passed through twenty-four generations. The tadpole stage of the common frog is prolonged in somewhat the same way by a radium tube of proper strength suspended in the water, but in this case eccentricities of growth occur and monsters are produced. When a strong radium tube is suspended over white mice they appear to be unaffected for several days, then the hair falls out and death results after a week or more. Rabbits act similarly. There are indications that weaker radium preparations have a stimulating effect upon the growth of the hair and the vital functions generally of these animals.

The effect of the rays from a strong preparation upon

the human body is similar to a severe burn, the chief difference being that nothing is noticed until some days after the exposure. To alter slightly a remark of Curie's, a pound of radium would probably destroy the human population of the planet, if each person were subjected to its influence for a time. For several days nothing would be noticed. Then the hair would fall out, the sight would be lost, the skin all over the body would become one continuous burn, and death would result.

IV. THE EMANATION.

What becomes of the radium atom when the particle which has produced the ray has been pitched off? What is the nature of the substance formed of the residual atomic fragments? It can no longer be radium, for a vast amount of chemical experience shows that a difference in atomic or molecular weight is always correlated with a difference in properties, and that the variation in the latter may be profound when the change in the former is relatively small. Compare, for instance, the properties of gold (atomic weight, 197·3) with those of mercury (atomic weight, 200), or those of lead (atomic weight, 207) with those of bismuth (atomic weight, 208).

Investigation shows that the residual substance is a *gas* which is continually escaping from radium compounds. It can be passed through glass tubes and preserved over mercury. When it is passed through a tube sunk in liquid air it is liquefied, producing a bright phosphorescence in the tube. It is *dense*, as shown by its rate of diffusion. It is somewhat soluble in water. It resembles helium and its allies in refusing absolutely to take part in any chemical reaction —all attempts to induce it to unite with other substances have failed. It is *poisonous*, for animals made to breathe air which has passed over a strong radium preparation die, although they are screened from the rays, and the air is entirely freed from any dust or powdered radium which might conceivably be carried with it. The lesions—as might be expected—are different from those produced by the rays. Instead of superficial burns we find congested and inflamed lung-tissue.

This gas is strongly radio-active, much more so than radium itself. Its atoms explode, shooting off particles just as the radium atoms do, but the atoms of the emanation are much more unstable, that is, a larger fraction of them explodes in a given time. Thus while it would require 1500 years for one-half of the atoms in a given mass of radium to disintegrate in this way, one-half of the atoms in a mass of the emanation would require only four days to do the same thing. Therefore, it will never be possible to prepare and handle the emanation in quantity, for the bombardment and the resulting development of heat would at once melt and destroy any vessel in which it might be placed.

V. EXCITED RADIO-ACTIVITY.

What becomes of the *emanation* when each atom of it has pitched off a particle, producing a ray? Something must be left, and for the reason stated above this something cannot be either radium or emanation. This time the substance is *solid*. It deposits on the surface of bodies and makes them temporarily radio-active. Thus every object exposed to the *emanation*—not the rays—acquires radio-activity, and retains it until the atoms of the invisible film of solid matter deposited on it have all exploded. Material makes no difference. Mica, copper, aluminium, cardboard, glass, ebonite—all become equally radio-active under the same circumstances. But it is a remarkable fact that if a metallic object—say a wire—which is exposed to the emanation is charged negatively, it acquires all the radio-activity, surrounding surfaces getting none of it.

This excited radio-activity is due to a film of solid matter on the surface, for it can be dissolved away by certain liquids, or wiped off with a piece of cloth or leather. Then the radio-activity is transferred to the liquid, the cloth or the leather, as the case may be. But the amount of solid matter present must be incredibly small, for it is totally invisible, and absolutely no gain in weight can be detected when a wire is made strongly radio-active. Thus this solid, of which an immeasurably small quantity can pro-

duce such great effects, must be thousands of times as active as radium itself. This means simply that its atoms are less stable, and a much larger proportion of them explodes in a given time. Therefore, the radio-activity must be transient. In fact, in half an hour half of the atoms of the film have undergone the change, and the excited radio-activity has fallen to one-half its original value.

VI. THE RADIO-ACTIVE PROCESS.

Thus the atoms of radium are unstable. They expel a positively charged particle, producing an α-ray, which shoots off, and the substance left behind is the emanation. The atoms of the emanation are still more unstable. Each of them expels an α particle, producing the solid, which is responsible for excited radio-activity. That the atoms of this solid also disintegrate we know—otherwise it would not be radio-active. But the changes which occur in the solid are complicated and difficult to study since the products are also solid and remain mixed with the substance from which they are derived. Rutherford* states that probably at least four successive changes takes place in the solid. It is important to note that the change of radium to the emanation, of the emanation to the solid and the first changes in the solid only expel α rays. It is only in the last transformation through which the solid passes that the β and γ rays are also produced. Here is Rutherford's tabular view of the series of transformations through which radium passes:

Substance.	Nature of Rays Produced.	Nature of Substance.
Radium.	α	Metal analogous to calcium.
↓		
Emanation.	α	Dense gas, inert, chemically condensed at —150° C.
↓		

* "Radio-activity," p. 326. This is an admirable book for one who wishes to take up the subject seriously.

Substances.	Nature of Rays Produced.	Nature of Substance.
First Solid.	α	Attaches itself to surfaces of bodies, from which it is driven off as vapor by a white heat. Soluble in some acids, but not in others.*
Second Solid.	No rays.	
Third Solid.	α, β and γ.	
Fourth Solid.	α and β	
Final product.		

It will be seen that there are six changes through which the restless radium atom passes before it finally finds peace in the production of a substance which is not radio-active, and, therefore, permanent. This final product is *helium. Both radium and helium are undoubtedly elements, and we have here the first case of the transformation of one element into another.*

This revolutionary fact—the transformation of radium into helium—was suspected by Rutherford, proved experimentally by Ramsay, and confirmed by sceptical German observers who expected to disprove it. Helium is a colorless, odorless gas, which is easily identified, and which, like the emanation, is inert chemically, refusing absolutely to take part in chemical changes. This change of one element into another is so entirely novel that it is desirable to examine the process, and to compare it with the ordinary chemical reactions, multitudes of which have been most carefully studied. In making this comparison we must remember that this is the first time the chemist has been permitted to *penetrate into the atom.* He has altered the grouping of atoms almost at will, and has produced upwards of a hundred thousand new groupings of the carbon atoms alone with those of other elements, but he has never before been able to study the disintegration of the atoms themselves, nor to effect any alteration in them.

Since, therefore, the radio-active process is so profoundly different from ordinary chemical transformations we should expect it to exhibit corresponding differences of behavior,

* This refers to the mixture which is obtained in experiment. The properties of the solids separately have not been determined.

and, as a matter of fact, it does, for there are at least two aspects of it which are so absolutely novel that they appear at first, to the trained chemical mind, bizarre and incredible.

Ordinary chemical changes are extremely sensitive to external circumstances; therefore by altering these circumstances they are easily controlled. Thus they proceed much more rapidly at high than at low temperatures. A rise of 10° C. on the average about doubles the speed. Many chemical processes are affected by light. Photography is based upon a mass of chemical changes which occur under the influence of light, and not in the dark. There are many reactions which are brought about by the aid of pressure, the electric current, Röntgen rays and so on.

Now the change through which radium passes and which ends in the production of helium is totally unaffected by external circumstances. It takes place at the same rate in absolute darkness as in the brightest light. Röntgen rays have no effect upon it. Its speed is exactly the same in liquid air at a temperature of about —190° C. as at a red heat. Even the rays from a radium preparation have no effect on the rate of change of another radium preparation. Similar statements might be made for all the factors which chemists are accustomed to employ to regulate the speed of chemical changes. The result is that the radio-active process is not under human control. It proceeds, paying no attention to externals, and we are powerless to bring it about or to stop it, to accelerate it or to retard it.

The other remarkable feature of radio-active change is the enormous amount of energy evolved during the transformation. The most energetic chemical process known (weight for weight) is the union of hydrogen with oxygen to form water. When 1 gram of water is produced, enough heat is formed to raise the temperature of 4,000 grams of water 1° C. No chemical change is known which liberates so much energy for the same weight transformed. Now the total heat liberated when 1 gram of radium transforms itself into helium through the successive steps which we have briefly traced is about *1,000,000 times as great as this.** It will be

* Rutherford, p. 336.

seen that the quantity of energy evolved in the radio-active change is of a different order from that liberated in ordinary chemical processes. In fact, a pound of radium would contain as much energy as several hundred tons of nitro-glycerine, and if the energy could all be liberated at once it would produce an explosion of unimaginable violence. Aside from the difficulty of obtaining so much radium, we must remember, however, that it will probably never be possible to quicken the rate at which its energy is emitted.

VII. RADIO-ACTIVITY IN GENERAL.

Thus the atom of radium contains an enormous supply of energy which is gradually liberated, and this liberation is coincident with a number of successive transformations of the substance which end in the production of helium. Several other elements are known which exhibit similar phenomena, but in a much less intense degree. The radio-activity of *thorium* has been carefully studied by Rutherford. In general character it is quite similar to that of radium. There is a *thorium emanation* which is intensely radio-active, which is transformed into a solid. This solid attaches itself to the surfaces of bodies and makes them temporarily radio-active, and so on. The chief difference is that in the case of thorium the changes take place about 1,000,000 times more slowly. This means that, if we imagine a quantity of radium and a quantity of thorium weighed off so as to contain the same number of atoms, about 1,000,000 times as many atoms would explode per second in the radium as in the thorium. It has been shown that, given a quantity of pure radium to start with, $\frac{1}{2000}$ of it would disintegrate per year. In 10,000 years practically all of it would have run its course. The rate of change of thorium is approximately given by mutiplying both of these periods by 1,000,000. But the total energy given off is probably of the same order in the two cases. It is only the speed which is different.

Are the atoms of all matter similarly constituted? Is radio-active change constantly taking place in ordinary matter? Are radium, thorium and the rest of the radio-active

elements simply those in which the number of atoms which disintegrate per second is so large that the process is easily detected? These are far-reaching questions. The obvious way of getting an answer to them is to test ordinary matter, like silver, platinum, copper, and so on, for radio-activity. Strutt has done this with great care, and his result is that all ordinary substances appear to possess a slight radio-activity. Unless this is due to a faint trace of a radio-element, it opens a vista of thought which staggers the imagination. A slow—inconceivably slow—process of evolution is taking place in the matter around us. Billions of times more slowly than radium, the elements are changing into something else. Matter has had a beginning and will have an end. So much we can see, but the beginning and end may remain forever unknown to us.

CENTRAL MANUAL TRAINING SCHOOL,
DEPARTMENT OF CHEMISTRY.

Franklin Institute.

[*Proceedings of the Stated Meeting, held Wednesday, February 15, 1905.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, February 15, 1905.

VICE-PRESIDENT WASHINGTON JONES in the chair.

Present, 42 members and visitors. Additions to membership during the previous month, 14.

The paper of the evening was read by Mr. John W. Hill, Chief Engineer of the Bureau of Filtration, Department of Public Works, Philadelphia, "On the Construction, Examination and Repair of the Torresdale Conduit."

The speaker illustrated his remarks very fully with the aid of lantern photographs.

The paper was discussed by Mr. Spencer Fullerton, Mr. E. M. Nichols, Dr. E. Goldsmith and the author.

On Dr. Goldsmith's motion the meeting passed a vote of thanks to Mr. Hill for his interesting communication.

Mr. John E. Alexander followed with a description of an improved phonograph of his invention, known as the "phonosphere," and gave a demonstration with the apparatus.

Adjourned.

WM. H. WAHL,
Secretary.

Committee on Science and the Arts.

(*Abstract of proceedings of the stated meeting held Wednesday, February 1, 1905.*)

DR. E. GOLDSMITH in the chair.

The annual election resulted in the choice of Dr. E. Goldsmith as Chairman for the current year.

The following reports were adopted:

(No. 2329.) *Knitting Machine.*—Edward Parkinson, Philadelphia.

ABSTRACT: This invention is protected by letters patent of the United States, No. 739,708, September 22, 1902, granted to applicant, and relates to that class of knitting machines known as single-plate straight knitting machines. The object of the improvements is: (1) to largely increase the capacity of machines of this class, and (2) to furnish a knitting machine with means whereby two threads will be successively engaged by the needles to form a fabric in different colors in either a plain stitch, in a tuck stitch, in a cross-stitch, or in any desired combination of these stitches; (3) to furnish means for the convenient and rapid substitution of different colored threads for any particular thread being operated upon, and (4) to furnish positive means for lifting and closing the latches of the needles.

The Committee's report concedes the correctness of these claims, and in recognition of the advance in the art which the invention represents, recommends the award to the applicant of the John Scott Legacy Premium Medal. (*Sub-Committee:* Henry R. Heyl, Chairman; Hugo Bilgram.)

(No. 2342.) *Automatic Hydraulic Letter-Copying Press.*—Walter A. Rosenbaum, New York.

ABSTRACT: This invention is covered by letters-patent of the United States, No. 756,530, April 5, 1904.

The report confirms applicant's statements that the invention is unique in its class, being entirely automatic in action, and actuated by the public water supply. The pressure applied is uniformly distributed over the surface of the press, and the amount of pressure may be multipled at will.

The water-power is led to two hydraulic cylinders, secured by means of brackets to the table or standard of the letter press. These brackets are hollow, to receive the pistons, and fulcrumed to each cylinder is a lever which, at its outer end, enters a slot in the bracket of the opposite cylinder, and bears on the top of the piston. The arrangement is such that the two levers lie parallel, and an equalizing lever is placed diagonally across them. The equalizing lever transmits pressure to a platen through a ball-and-socket joint, the socket being formed with a circular rubber cushion to take up any inequalities in the thickness of the book, and render the pressure uniform over the entire book surface. The copying book is pressed upward by the platen against a pressure plate, which is mounted on extensions of the cylinder bracket. The flow of water in the cylinders is controlled by a three-way

valve, which is operated by a small hand-wheel conveniently placed near the top of the table.

The report concludes that the press is a useful and practical device, well designed and constructed for its intended purpose, and that it will meet a long-felt need in offices where much copying is required and high pressure is needed. The award of the John Scott Legacy Premium and Medal is recommended. (*Sub-Committee:* Geo. S. Cullen, Chairman; James S. Rogers.)

(No. 2348.) *Safety-Elevator Devices.*—Standard Elevator Interlock Company, Philadelphia.

(Report protested by applicant.)

(No. 2345.) *Products* of the Flexible Compound Company, Philadelphia. (Progress.)

(No. 2354.) *Railway-Car Cuspidor.*—Emanuel Metzger, Kingston, N. Y. (An advisory report.) W.